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**EFFECTIVENESS OF SEED TREATMENT IN PREVENTING
THE SPREAD OF FUSARIUM SPP. THROUGH INFECTED
SEED**

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**Assessment of chemical seed treatments for preventing the spread of
Fusarium graminearum from infected seed under field and
controlled-environment conditions**

***Saskatchewan Agriculture Development Fund
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FINAL REPORT

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INTRODUCTION

For over a decade, Fusarium head blight (FHB), caused mostly by *Fusarium graminearum* (teleomorph *Gibberella zeae*) has been causing significant losses to the grain industry in the eastern Canadian Prairies (Gilbert and Tekauz, 2000). There has been little or no damage caused by this disease in eastern Saskatchewan in the last few years due to dry conditions during anthesis and kernel development not conducive to its development (Pearse et al., 2007a, 2007b). However, its potential spread further westward is of major concern to wheat and barley growers (Fernandez et al., 2005).

The main source of inoculum for infection of crops are infected residues on the ground (Sutton, 1982). In addition, infected seed left behind in a field after seeding of an infected seed lot or after harvest of a crop affected by FHB can also contribute to inoculum for infection of the following crop. Inch and Gilbert (2003) showed that infested seed can harbour *F. graminearum* for at least two years and that the pathogen can produce perithecia on infested seed left on the soil surface.

Previous studies have shown that the same *Fusarium* spp. that cause FHB can also cause seedling blight and crown/root rot in wheat and barley (Fernandez and Jefferson, 2004; Fernandez et al., 2007a, 2007b). Fernandez and Chen (2005) showed that isolates derived from infected wheat spikes had the same pathogenicity on wheat seeds at planting or on seedlings as isolates derived from infected ground or underground tissue.

In addition, the same species responsible for FHB can also be harboured by noncereal species. Fernandez (2007) isolated FHB-causing species, including *F. graminearum*, from discolored roots of pulse and oilseed crops grown in Saskatchewan in rotation with cereal crops. In a controlled-environment study, Chongo et al. (2001) demonstrated infection of seed and seedlings of noncereal species from an adjacent source of *F. graminearum*. Fernandez (2001) showed that *F. graminearum* isolated from cereal and noncereal crops had the same pathogenicity on spikes and roots of wheat as isolates from infected cereal spikes.

Seed-to-seedling transmission of *F. graminearum* was demonstrated by Duthie and Hall (1987), Klein and Burgess (1987), and Halfron-Meiri et al. (1979). Duthie and Hall (1987) reported that *F. graminearum* was transmitted from seed to stem bases of wheat with an efficiency of 55 to 94%. In addition to the impact on plant growth and yield that root and crown infections by this pathogen might have, seedling infections might result in the formation of reproductive structures in the lower culms which could lead to head infections of the same crop even if there was no wheat planted previously in that field for a number of years (Fernandez, 2001). Despite the transmission of fungal infection from the seed to seedlings, studies have shown no association between seed infection and FHB development in the year the infected seed was planted (Duthie and Hall, 1987; Gilbert et al., 2003; Jones, 1999; Wong et al., 1992). Thus, the most immediate impact of seed infection by *F. graminearum* is reduced germination and plant emergence in the field, which could result in yield reductions (Martin, 2005; Wong et al., 1992).

For wheat-growing areas that are still for the most part free of *F. graminearum*, such as the western regions of the Prairies, the most important concern is the potential for infected seed brought into the area to help establish *F. graminearum* as a result of infection of seedlings, root and crown/lower stem tissues, or via the release of ascospores or macroconidia produced from seed left on the soil surface. Infected plant tissue as a direct result of planting infected seed would result in crop residues on which perithecia can form and release ascospores in subsequent growing seasons which could then cause head infections of cereal crops. Repeated planting of *F. graminearum*-infected seed could result in accumulation of soil inoculum in areas where this disease is absent or present at low levels. The impact of this on FHB development would be highly dependent on environmental conditions during the plant stage at which the crop is most susceptible.

Until more resistant varieties are developed, it is important to reduce the potential impact of FHB by slowing down its introduction to western Saskatchewan and Alberta fields. It is therefore of interest to determine the effectiveness of seed treatments in preventing the spread of *F. graminearum* which could result from planting an infected seed lot. This will assist with the

development of strategies to prevent or restrict the movement of this pathogen into areas where it is still rare or absent.

Although there have been previous studies done on the effectiveness of seed treatments against *Fusarium* infections of cereal crops, results have not been consistent. In many of these studies, it was also not possible to separate seed-borne from soil-borne infections, or the tests were aimed at soil-borne infections only. In addition, some of the studies done on the effectiveness of seed treatments were *in vitro*. Response of seed infection to a chemical under *in vitro* conditions might not necessarily translate into a similar effect in the field. Mihuta-Grimm and Forster (1989) reported that although there were differences between seed treatments and the untreated control in the number of seeds colonized by *Fusarium* in *in vitro* tests, in the field stand counts of seedlings from treated seeds were no significantly different from those of the untreated controls.

Jones (1999) reported that some of the seed treatments tested controlled seedling blight in wheat caused by seed-borne *Fusarium* infections, and thus improved stands of a *Fusarium*-damaged seed lot. However, Duthie and Hall (1985) and Klein and Burgess (1987) indicated that seed treatment may not have the ability to prevent seed-to-seedling transmission. Duthie and Hall (1985) reported that emergence of plants derived from winter wheat seed infected by *F. graminearum* was higher when seed was treated than untreated but this difference was not statistically significant. Schaafsma and Tamburic-Ilincic (2000) and Schaafsma et al. (2001) reported that none of the seed treatments tested affected emergence, number of tillers or yield of a winter wheat seed lot infected by *F. graminearum*, whereas Klein and Burgess (1987) reported that seed treatments did not affect the incidence of infected plants, whitehead formation, seedling emergence or yield of wheat plants derived from *F. pseudograminearum*-infected seed.

Similar results were reported for soil-borne infections. Celetti and Hall (1987) reported that none of the seed treatments used were effective, or consistently effective, in reducing *Fusarium* infections of crowns of winter wheat, and that heads per m² and grain yield of winter wheat was not affected by the seed treatments. A protectant fungicide (Maneb), alone or in combination with systemic

fungicides, reduced the total incidence of *Fusarium* in crowns in the fall in both trials, but did not consistently affect the pathogenic species.

Other studies have shown a positive effect of seed treatments on crop performance in the presence of *Fusarium* seed infections or soil inoculum. Gilbert and Tekauz (1995) reported that fungicide treatments tended to improve emergence of *F. graminearum*-infected seed under greenhouse conditions. Schaafsma and Tamburic-Ilincic (2005) reported that some of the seed treatments tested improved the emergence of *F. graminearum*-infected winter wheat seed and increased the density of spikes relative to that of the untreated control, and that most treatments resulted in more tillering and higher grain yields than the untreated control. When seeds were planted with the addition of *Fusarium* inoculum, Martin (2005b) reported that all seed treatments tested increased emergence of spring wheat, and most resulted in increases in grain yield over the inoculated control. Lamprecht et al. (1990) reported that seed treatments reduced pre- and post-emergence damping-off of wheat seedlings when inoculated with *F. avenaceum* or *F. pseudograminearum* but were less effective in reducing disease severity, or could even increase it.

There have also been studies on the effect of seed treatments on crop performance and grain yield of poor quality seed lots due mainly to infection by pathogens other than *Fusarium*, or to prevent seedling blight/root rot derived from soil-borne inoculum. Results from these studies on the effectiveness of seed treatments in improvement of emergence and yield have not been very consistent either. Treatment of barley seed from different sources infected with different levels of *Bipolaris sorokiniana* resulted in inconsistent increases in yield and kernel weight in field trials (Sterling et al., 1977). Chinn (1978) reported that only one of the eight seed treatments tested reduced common root rot caused by *Cochliobolus sativus* in seedlings and mature spring wheat plants at two locations and in a greenhouse test. Similar results were obtained by Verma et al. (1986) who reported that the three seed treatments tested resulted in greater root rot suppression in spring wheat cultivars and locations with potentially higher disease ratings, and increased the proportion of spring wheat plants that produced fertile heads; however, the effect of seed treatments on grain yield was small and not significant. Martin and Matters (2001) reported that all seed

treatments tested showed a significant effect on seedling blight/root rot of barley relative to the untreated control, but none affected yield or kernel weight. Martin and Matters (2002a) reported no effect of seed treatments on emergence, yield or kernel weight of barley, although all treatments resulted in significant reductions in root rot, whereas Martin and Matters (2002b) reported that most seed treatments tested reduced root rot in spring wheat, but in most cases there was no effect on kernel weight. Martin (2005a) reported no impact of seed treatments on emergence or root rot severity of barley. Gonzalez and Trevathan (2001) reported that seed treatment improved the seedling stand of soft red winter wheat in one of the two years of the study over the untreated control, but did not result in statistically significant differences in yield or kernel weight in either year of the study. However, they did find a significant correlation between seedling stand and yield. Clark (1977) and Verma (1983) reported that seed treatments did not have an effect on the emergence and/or grain yield of wheat and barley.

The objectives of this study was to determine (1) the effectiveness of chemical seed treatments in preventing the spread of *F. graminearum* from infected spring wheat and barley seed to plant tissue under field and controlled-environment conditions, and (2) whether seed treatments can improve the performance of crops derived from *Fusarium*-infected seed lots. Most of the seed treatments used were registered for use on barley and wheat seed in western Canada (Saskatchewan Agriculture and Food, 2006), while the rest were experimental products not yet registered. The mode of action of the chemical seed treatments used is either systemic or contact. The locations selected for this study, all in eastern Saskatchewan, had had FHB caused by *F. graminearum* and other *Fusarium* spp. in previous years.

MATERIALS AND METHODS

Environmental conditions

The monthly total precipitation (mm) and mean temperature (°C) from April to August, and long term (1971-2000) means are presented in Table 1. Data were obtained from Environment Canada (2007). Because of the proximity between the Indian Head and Sintaluta locations (about 10 km), data from Indian Head was also used for the Sintaluta site. There were no weather stations in Canora, so data from the closest site, Good Spirit Lake located at < 20 km km from Canora, were used.

Field trials

During the winter of each of the years in which these trials were conducted, numerous seed lots were obtained from commercial fields in different locations where FHB had occurred the year before. A seed sample was plated on modified PDA to determine percent infection by *F. graminearum*. Most of the seed lots were either not infected by *F. graminearum* or infection levels were very low. The seed lots with the highest levels of infection were selected each year. Due to the limited availability of seed lots with *F. graminearum* infection, different cultivars of barley, durum and common wheat were used in the three years, and not all crop species were tested every year (Table 2). *Fusarium graminearum*-infected seed lots of barley (2004 and 2005), durum (2003 and 2004), and common (2003 to 2005) wheat cultivars susceptible to FHB (Saskatchewan Agriculture and Food, 2006) had all been infected under natural field conditions.

Infected seed lots were treated with chemical fungicides currently registered in Canada at recommended rates (Table 3). There were also experimental products from two companies tested. Controls consisted of seed from the same infected lot but not treated with any fungicide, and seed from an uninfected lot of the same cultivar grown in a FHB-free region. The latter was used to differentiate between seed-borne and soil-borne fungal infections.

Trials were established at various locations in eastern Saskatchewan: Canora, Indian Head, Sintaluta, and Redvers (Table 2). The soil types were Naicam silty clay loam at Canora (Black soil zone), Indian Head heavy clay at Indian Head (Thin Black soil zone), Oxbow loam at Sintaluta (Thin Black soil zone). However, complete data sets were not always obtained from all locations.

In 2003, trials were conducted as a two factorial RCBD with seed treatments and crops being the two factors. To facilitate the management of the crops in 2004 and 2005 the trials had a split-plot design with crops as main plots and seed treatments as sub-plots, with four replicates each. The plot size was 1.2 m wide and 5.5 m long at Redvers, 1.2 m wide and 3.7 m long at Canora and 2.4 m wide and 9.8 m long at Indian Head and Sintaluta. Each plot had 4 rows with a 27 cm row width at Redvers, 4 rows with a 30 cm row width at Canora, and 10 rows with a 20 cm row width at Indian Head and Sintaluta. Plots were seeded directly into standing stubble using a low disturbance no-till plot drill with a row spacing ranging from 20 cm (Indian Head and Sintaluta) to 27 cm (Canora and Redvers). Seeding depth was between 4 and 6 cm. Seeding rates were adjusted based on percent germination tests done in the spring to achieve a target plant density of 200 plants m^{-2} . In most cases, the germination rate for each seed lot was provided by the supplier which was verified by germinating 50 seeds on wet filter paper in a Petri dishes twice (Table 2). Seeding was done between the third and fourth week of May.

Nitrogen, phosphorous and potassium applications were based on soil test recommendations for each site in each year (Saskatchewan Agriculture and Food, 2006). The amount of N applied ranged from 68 to 100 kg ha^{-1} . The amount of P_2O_5 ranged from 20 to 45 kg ha^{-1} and K_2O ranged from 10 to 17 kg ha^{-1} . An in-crop herbicide for broadleaf weed control was applied using recommended application rates and timings appropriate for the weed spectrum and environmental conditions. A second herbicide was used to control grass type weeds except at Indian Head in 2005 where a herbicide to control grass type weeds was not required. The specific herbicides used at each site depended on the weed spectrum.

The plant density was measured at Zadoks GS 10-13 (Zadoks et al., 1974). Number of seedlings per m² was calculated by counting the number of seedlings in two 1-m sections of different rows taken at random within each plot. Number of spikes per m² was determined between heading and maturity (GS 60-90) by counting two 1-m sections of different rows taken at random within each plot. The number of spikes per plant was calculated using plants per m² and spikes per m². Plant height was measured between anthesis and maturity (GS 60-90) at two different spots in each plot. The number of days to heading was also measured, a plot was considered to be headed when 50% of the heads on the main stems were fully emerged. Number of days to maturity were measured when the kernel could be permanently dented by a finger nail. Lodging was determined each year on a scale of 1 to 10 with 1 being no lodging and at 10 100% of the plot was flat.

At stem elongation (GS 31-33), 50-75 plants from the second row in from the outside of the plot were removed carefully, dried at room temperature and sent to the Semi-arid Prairie Agricultural Research Centre, at Swift Current where they were kept in the cold until analyzed for common root rot (CRR) in the fall. Roots were washed thoroughly under tap water and dried at 40°C. Subcrown internodes were then carefully excised and rated for extent of brown to black discoloration (slight=1 to 25%, moderate=25 to 50%, and severe=>50% discoloration) (Fernandez et al, 2007a). Percentage of subcrown internodes with severe (CRR3), and moderate or severe (CRR23), discoloration was then calculated for each plot. A piece of each discolored subcrown internode (1-2 cm) was surface-disinfested, and plated on modified potato dextrose agar for fungal identification (Fernandez and Chen, 2005). Fungi growing out of each piece of subcrown internode tissue were identified after incubation for 7-10 days at 22°C/18°C with a photoperiod of 16 h light and 8 h dark. Percent isolation of each fungus per plot was calculated based on the total number of subcrown internode pieces that were plated.

Plots were harvested after physiological maturity from late August to early October, depending on the year and location. Grain yield was recorded on a clean grain basis corrected to 13% seed moisture content. Kernel weight was calculated by weighting between 700 to 1000 kernels using a seed counter. Number of kernels head⁻¹ was calculated from the number of spikes m⁻², grain yield

and kernel weight. Test weight was measured using the methodology specified by the Canadian Grain Commission (2006), and protein concentration was determined following procedure reported by Wang et al. (2002). Not all measurements during plant growth and harvest were taken at all locations in each year of the study.

Growth-chamber trial

Fusarium-infected seed of the common wheat cultivar Superb lot used in the 2005 field trials were used for this study. However, as many of the healthy-looking seeds as possible were removed from the original seed lot to increase the percentage of infected seed. Seed were treated with each of eight chemical seed treatments, and controls consisted again of untreated infected seed, and seed from an uninfected lot of the same cultivar.

Seeds treated with the chemical seed treatments were individually planted at a depth of 4 cm in each cell of 6-pack plastic pots (each cell was 5 cm x 5 cm x 5 cm). Cells were filled to the top with a soil-less growing mix (No. LB2-Basic Mix consisting of 70-8-% of sphagnum peat moss in addition to perlite, dolomitic limestone, and gypsum) packed tightly. Each pot represented a replicate (6 cells each), and there were five replicates per treatment, arranged in a randomized complete block design. The test was conducted twice.

After planting, pots were watered with tap water for about three days, and from then until harvest they were watered daily with a nutrient solution containing 200 ppm of 20-20-20 NPK. Each day, the pots were placed on metal trays filled with fresh nutrient solution, and when moisture appeared on the surface of the pots they were removed from the solution and placed on inverted plastic trays to allow for adequate air circulation. After seedlings were at about the 4-5 leaf stage, watering from the top was also needed to provide adequate moisture. Pots were incubated at 15°C constant until the 3-4 leaf stage, and afterwards at 22°C day and 18°C dark until harvest. Photoperiod throughout the duration of the trials was 16 hours light/8 h dark.

Seedling emergence was recorded daily after planting. Ten days after planting, the number of leaves per plant was recorded. Harvest was done when most plants had reached at least the booting stage (GS 46). At harvest 46 d after seeding, the number of plants that had died after emergence, the number of tillers in each plant still alive, and growth stage were recorded. This was done using a 1-4 rating scale: 1: plant not yet at booting stage, 2: plant in boot, 3: up to 50% of spike out (GS 55); 4: spike fully emerged (GS 59).

At harvest, plants were removed from each cell carefully, washed thoroughly under tap water and allowed to dry at room temperature. Outer sheets were carefully removed before the basal shoots were scored for discoloration. Subcrown internodes and crowns/basal shoots were rated for extent of brown to black discoloration using a 0 to 4 scale (0: no discoloration, 1: <25% of tissue discolored; 2: 25-50% of tissue discolored; 3: >50% of tissue discolored; 4: tissue was rotted and decomposing). The extent of discoloration from the crown up the shoot of each plant was also recorded using a 0 to 4 scale (0: no discoloration, 1: discoloration extending to below the first stem node, 2: discoloration extending to the first node, 3: discoloration extending to between the first and second nodes, 4: discoloration extending to the second node).

After plants were scored for discoloration, segments (1 to 2 cm each) of discoloured subcrown internodes and crowns/basal shoots were individually plated on modified PDA as above, after surface disinfection. Subcrown internodes and crowns/basal shoots of seedlings that had died before harvest were also plated. Fungi growing out of the plant tissue were identified after 7-10 d of incubation under the same conditions as above. The number of isolations of each fungus from tissue of plants that were still alive at harvest was divided by the number of surviving plants in each pot.

Statistical analyses

The agronomic data collected in the field trials were analysed using the PROC MIXED procedure

of SAS (Littell et al., 1996). Due to the different seed lots and cultivars used in each year of the study, the data were analysed separately for each year. Seed treatment, plant species, and location were considered fixed effects and replicate was considered a random effect. Fixed treatment effects were declared significant at $P \leq 0.05$. Mean differences were assessed using the Tukey-Kramer multiple comparison test to limit the experimentwise error rate to 5%. When there was a significant seed treatment x location or seed treatment x plant species interaction the seed treatment means were compared at each location or within each plant species. A similar approach was used for the three way interaction, seed treatment x location x plant species, with the seed treatment means being compared within each plant species at each location. The means for any significant plant species x location interactions were compared across plant species and location.

Exploratory analysis of the common root rot data found variance heterogeneity among the different locations. An arcsine transformation was used to correct this problem but did not change the results when analysed using the PROC MIXED procedure of SAS (Littell et al., 1996). Therefore the common root rot ratings were analysed with untransformed data using the PROC MIXED procedure of SAS. The Tukey-Kramer multiple comparison test was used to compare means.

Exploratory analysis of fungal isolate data revealed non-normal data distributions and variance heterogeneity. Data, with '1' added to all data points to eliminate '0's', were analyzed with the PROC GLIMMIX procedure of SAS (SAS Institute, 2005) with all effects considered fixed and a negative binomial/log distribution/link function model specification. A Chi-Square/DF model fit criteria was used to ensure that the model parameterizations provided adequate fit. Means were presented on a back-transformed scale and mean differences were assessed using Tukey-kramer adjustment multiple comparison test. Fixed treatment effects were declared significant at $P \leq 0.05$.

For the controlled-environment study, data were analysed with the PROC GLM procedure of SAS. All percentage data were arcsine-transformed, and analyzed by ANOVA.

RESULTS

Environmental conditions

Canora was wetter than normal in May of 2004 and 2005, and in June and July of 2005 (Table 1). Indian Head/Sintaluta was also wetter than normal in May of 2004 and June of 2005, but drier than normal in May and June of 2003. Indian Head/Sintaluta was drier than normal in July of 2003. Redvers was wetter in May of 2004 than May of 2005, but wetter in June of 2005 than June of 2004. In July, Redvers was wetter in 2004 than 2005.

Overall, the growing season in 2003 and 2005 was warmer than in 2004 (Table 1). Canora was cooler than normal in May of 2004 and 2005, especially in 2004, and in June of 2004, whereas July of 2005 was warmer than the long-term mean and that July of 2004. Indian Head/Sintaluta was also cooler than normal in 2004 and 2005, especially in 2004 for May and June.

Field trials

Most of the seed lots used in the field trials across the three years had low levels of FDK which is what would be expected producers to seed in Saskatchewan. The exception was the Superb seed lot used in 2005 which had a higher level of FDK than the other lots, and likely higher than what producers would normally plant in this region. However, plating of a random sample of seed from all lots revealed that in most cases seed that were not visibly damaged were also infected by *F. graminearum*. Based on the plating of seeds on modified PDA, all seed lots were infected by *F. graminearum* (Table 2); other *Fusarium* spp. were also isolated from the seed lots at lower levels. In addition, other fungal pathogens such as *C. sativus* and *Pyrenophora tritici-repentis* were also present; whereas *Alternaria*, a common saprophyte, was isolated often from seed.

The seed lot with the highest percent infection by *F. graminearum* was the common wheat Superb

used in 2005; followed by the Kyle and Superb seed lots used in the 2003 trials. None of the untreated uninfected seed lots were infected by *F. graminearum* or other *Fusarium* pathogen, and had percent germinations of 85% to 99%.

Agronomic performance

Table 4 presents an overall mean of the various parameters measured. Overall, seedlings and spikes per m² were higher in 2005 than in the previous two years. Kernels per spike and per m², and plant height were highest in 2004. Grain yield and thousand kernel weight were lowest in 2003, with the latter being highest in 2005. Test weight was highest in 2003.

2003: The location and/or plant species effects were significant for all of the parameters measured, and in most cases there was a significant location X plant species interaction (Table 5). There was greater seedling emergence at Sinaluta than Indian Head, and at both locations common wheat had more spikes per m² than durum wheat. The highest mean number of spikes per m² was observed at Sinaluta. For both locations combined, common wheat also had more spikes per plant but fewer kernels per spike than durum wheat. For both crop species, plant height was greater at Sinaluta than Indian head, and at both locations the common wheat plants were shorter than the durum wheat plants. Grain yield differed between plant species only at Indian Head, with durum yielding more than common wheat, whereas protein concentration was higher for common than durum wheat at Indian Head. Kernel weight and test weight were in general lower at Sinaluta than Indian Head. Kernel weight at both locations and test weight at Sinaluta were lower for common than durum wheat.

The seed treatment effect was significant only for seedlings per m², spikes per plant and plant height (Table 5). The untreated infected control did not differ from the untreated uninfected control. In most cases, there was no difference between the untreated infected control and the seed treatments, except for the JAU treatment which had more seedlings per m² than the untreated controls. The number of seedlings per m² in the untreated uninfected control was lower than for any of the seed treatments. In most cases, the number of spikes per plant in the seed treatments was not

different from the untreated controls, except for the Dividend XL RTA, JAU+Raxil250 and BASF2 treatments where the means were lower than in the untreated uninfected control. In most cases, there were no differences in plant height, except for plants in the Gemini and BASF1 treatments, which were taller than in the untreated uninfected control.

2004: For most of the parameters measured, there was a significant location X plant species interaction (Table 6). For all three crop types, there were consistently fewer seedlings per m² at Sinaluta than at the other two locations, with Canora having the highest number of seedlings per m² for barley and durum wheat. Number of days to heading was lower for Canora and highest for Sinaluta. For spikes per m², location and plant species were significant. The mean number of spikes per m² was highest at Canora and lowest at Sinaluta, and highest for common wheat and lowest for barley. For barley and durum wheat, there were more spikes per plant at Sinaluta than Canora. The number of kernels per spike was higher at Sinaluta than at the other two locations for barley and common wheat. Kernels per m² was lower for Sinaluta than Canora for durum and common wheat. There was also a lower grain yield at Sinaluta than at the other two locations for all crop types, which was in most cases attributed to lower kernel weight. The lowest test weight was observed at Sinaluta. Plant height was greater at Indian Head than at the other two locations for barley and common wheat, and greater at Canora and lowest at Sinaluta for durum wheat.

The plant species X seed treatment interaction was also significant for seedlings per m² (Table 6). Significant differences among treatments were only observed in common wheat (data for barley and durum wheat not presented). There was no difference between the untreated infected and the untreated uninfected control. There was no difference among seed treatments, and in most cases there was also no difference between seed treatments and the untreated infected control. For common wheat, Charter 2.5 was the only seed treatment that had significantly more seedlings per m² than the untreated infected control. There were fewer seedlings per m² in the untreated uninfected control than in some of the seed treatments.

2005: The location X plant species interaction was again significant for most of the parameters

measured (Table 7). For both barley and common wheat, the mean number of seedlings and spikes per m² were lower at Canora than Indian Head. The number of spikes per plant was greatest at Redvers and lowest at Canora, whereas the number of kernels per spike was greater at Canora than at the other two locations. Plant height was greatest at Indian Head for both crop types. Grain yield was highest at Indian Head for barley, and highest at Canora for common wheat. Kernel weight was lowest at Redvers for barley, and lowest at Indian head and highest at Canora for common wheat.

The seed treatment effect was significant for the number of kernels per m², plant height and grain yield (Table 7). Although the untreated infected control had fewer kernels per m² and lower grain yield than the untreated uninfected control, in most cases the means for the controls were not different from those of the chemical seed treatments. Vitaflo 280 (high) and Bayer1 were the only treatments that had a greater number of kernels per m² and grain yield than the untreated infected control. Plants in the Vitaflo 280 (high) treatment were also significantly taller than in the untreated infected control.

There was also a plant species X seed treatment interaction for number of seedlings per m² and spikes per plant, and a location X plant species X seed treatment interaction for days to heading (Table 7). Seed treatment had a significant effect on the number of seedlings per m² only for common wheat (barley data not presented). The untreated uninfected control had more seedlings per m² than the untreated infected control but was similar to that in some of the chemical seed treatments. There were more seedlings per m² in the seed treatments than in the untreated infected control, with the exception of Charter 2.5. In contrast, there were more spikes per plant in the untreated infected control than in the untreated uninfected control or any of the seed treatments; whereas the untreated uninfected control also had similar number of spikes per plant than most of the seed treatments.

There was a significant location X plant species X seed treatment interaction for days to heading and test weight (Table 7). The effect on days to heading should be attributed to differences among locations given that within each location there were no significant differences among treatments.

The effect of seed treatment on test weight varied between Canora and Redvers for common wheat, although in most cases these were not significantly different from the untreated infected control. There were no differences among seed treatments for barley (data not presented). Test weight at Indian Head did not differ among seed treatments and is not presented either. There were differences for test weight among seed treatments at Canora and Redvers but these differences were not consistent.

Common root rot

For all years, crowns from the plants sampled from the field trials at the stem elongation stage showed very little discoloration, therefore they were not analyzed for severity of discoloration or fungi present. Thus only subcrown internodes were rated for discoloration and plated for fungal identification.

For root rot severity, CRR3 (percentage of subcrown internodes with severe discoloration) was similar among years, whereas CRR23 (percentage of subcrown internodes with moderate or severe discoloration) was highest in 2005 (Table 4).

2003: The interaction plant species X seed treatment for disease severity (CRR23 and CRR3) was significant (Table 8). In most cases, there was no difference between the untreated infected control and the seed treatments. The untreated uninfected control had a lower CRR severity than the untreated infected control in common wheat but not in durum wheat. Only plants in the Gemini and BASF2 treatments for common wheat, and Raxil 250 FL and JAU+Raxil250 treatments for durum wheat, had a lower disease severity than those in the untreated uninfected control.

2004: The location X plant species interaction was significant for CRR23 and CRR3 (Table 9). At Canora, there was a greater disease severity than at the other locations for barley, but disease severity was the greatest for durum and common wheat.

The effect of seed treatment was also significant for disease severity (Table 9). However, in most

cases disease severity in the chemical seed treatments did not differ from that in the untreated infected control or the untreated uninfected control. The untreated uninfected control was only significantly lower than in the untreated infected control for CRR3. The only treatments that had a significantly lower CRR23 and CRR3 than the untreated infected control were Dividend XL RTA and BASF3, whereas Maxim 480 FS, BASF4 and Bayer1 had a lower CRR3 than the untreated infected control.

2005: The location X plant species interaction was significant for both CRR23 and CRR3 (Table 10). Percent CRR23 was higher at Redvers than at Indian Head for both plant species, whereas CRR3 was higher at Redvers than Indian Head for common wheat.

The effect of seed treatment was significant for CRR3 (Table 10). However, none of the seed treatments differed in percent CRR3 from the untreated infected control, and the untreated infected and uninfected controls were not significantly different from each other either.

***Fusarium* and other fungal species isolated from subcrown internodes**

Fusarium was overall the most common genus isolated from subcrown internodes (Table 4). This was followed by *C. sativus*. *Fusarium* spp. were most frequently isolated in 2003 and least in 2004, whereas *C. sativus* was most frequent in 2004 and least frequent in 2003. Among the *Fusarium* spp., *F. graminearum* and *F. culmorum* were most frequently isolated in 2003, whereas *F. avenaceum* was most frequently isolated in 2005. The weak pathogens/saprophytes *F. equiseti* and *F. acuminatum* were most common in 2003. *Microdochium bolleyi* was also most common in 2003, while *Alternaria* spp. were isolated with similar frequency in all years of the study.

Other fungi isolated at lower levels from subcrown internodes included *F. poae*, *F. sporotrichioides*, *Cladosporium* spp., *Epicoccum nigrum*, *Pyrenophora tritici-repentis*, *P. teres*, *Rhizoctonia* spp., *Penicillium* spp., *Phoma* spp., and *Trichoderma* spp.

For all three years of field trials, most of the interactions among location, plant species and seed

treatment were significant (Table 11).

2003: *Cochliobolus sativus* was present at higher levels at Sinaluta than Indian Head in both durum and common wheat, whereas *F. avenaceum* was present at higher levels at Sinaluta than Indian Head in common wheat (Table 12).

For most fungi, there were no significant differences between the untreated infected control and the untreated uninfected control, regardless of the location or plant species (Table 12). The exception was *F. graminearum* which was in most cases present at lower levels in the untreated uninfected than in the untreated infected control.

For the most part, percent isolation of fungi from the various chemical seed treatments did not differ from isolations from the untreated infected control (Table 12). The exception was *F. culmorum* at Indian Head which was present at lower levels in the Charter 2.5, JAU, JAU+Raxil250, Raxil 250FL, and Raxil 250+Trilex FL treatments than in the untreated infected control. This pathogen was also present at lower levels in durum wheat in most of the seed treatments, especially JAU and JAU+Raxil 250, than in the untreated infected control.

For *F. graminearum*, none of the seed treatments resulted in significantly lower levels of isolation relative to the untreated infected control at Sinaluta (Table 12). However, levels of this pathogen in common wheat in the Gemini, BASF1 and BASF2 treatments were less than 0.1% and similar to those in the untreated uninfected control, in addition to being lower than for most of the other seed treatments. At Indian Head, common wheat plants in the Gemini, BASF1 and BASF2 treatments had significantly lower levels of this pathogen isolated from discolored subcrown internodes than those in the untreated infected control.

For total *Fusarium* spp., only plants in the Gemini and JAU+Raxil 250 treatments had lower levels of isolates of this genus than those in the untreated infected control at Sinaluta, whereas for both locations combined, durum wheat in the JAU+Raxil 250 treatments and common wheat in the

Gemini treatments had lower levels than the untreated infected (Table 12).

For *M. bolleyi*, only plants in the Raxil 250+Trilex FL treatment had lower levels than those in the untreated infected control (Table 12).

2004: *Fusarium culmorum* was present at higher levels at Indian Head than at the other two locations (Table 13). *Fusarium oxysporum* was present at the highest levels in barley followed by common wheat at Sintaluta. Total *Fusarium* spp. were present at higher levels at Sintaluta than at the other two locations, and were more common in barley and least common in durum wheat. *M. bolleyi* was present at the lowest levels in barley at Canora and Sintaluta, and in durum wheat at Indian Head.

For most of the fungal species where there was a significant location X plant species X seed treatment interaction, percent isolation among seed treatments in each location and/or plant species did not differ significantly, suggesting that the interaction was due to differences among locations and/or plant species and not seed treatments (Table 13). The exception was *F. oxysporum* which was present at higher levels in the Dividend XL RTA, Raxil T and BASF4 treatments than in the untreated infected control at Sintaluta. Total *Fusarium* spp. were only significantly higher in the Dividend XL RTA than in the Gemini treatment of durum wheat, and higher in the Raxil T and BASF3 treatments than the untreated uninfected control for common wheat.

2005: As for 2004, the interaction location X plant species was in some cases significant (Table 11).

Cochliobolus sativus was present at higher levels in subcrown internodes of barley than in those of common wheat at both locations, and its percent isolation was higher at Indian Head than Redvers for barley, but lower at Indian Head than Redvers for common wheat (Table 14). For *F. equiseti*, its percent isolation from common wheat was higher at Redvers than Indian Head.

As in previous years, the percent isolation of most of the fungi did not differ between the untreated

infected and the untreated uninfected controls (Table 14). The exception was again *F. graminearum* whose percent isolation from common wheat was higher in the untreated infected than the untreated uninfected control at both locations, although this difference was not statistically significant at Redvers.

In most cases, there were significant interactions of seed treatment with location or plant species, or both (Table 11). For *C. sativus*, levels were lower in the Dividend XL RTA treatment than in the untreated infected control at both locations, and lower in the Raxil T treatment than the untreated infected control at Indian Head (Table 14). The lower isolation of this fungus in the Dividend XL RTA treatment was observed in both barley and common wheat, whereas the lower isolation in the Raxil T treatments was observed only in common wheat.

For *F. graminearum*, only in common wheat at Indian Head were its levels significantly lower in the Dividend XL RTA treatment than in the untreated infected control (Table 14).

For the rest of the fungi, there were no significant differences among the seed treatments within each location or plant species or location/plant species suggesting that the interactions were due to differences between locations, plant species, or among location/plant species (Table 14).

Growth-chamber trial

The Superb infected seed selected for the growth-chamber trial had a percent infection by *F. graminearum* of 78%. The only other *Fusarium* pathogen present was *F. avenaceum* at 1%, whereas *C. sativus* was present at 5% and *P. tritici-repentis* at 7%. *Alternaria* was present in 37% of the selected seed.

The untreated infected seed took a longer time than the untreated uninfected seed to start emerging, and for half of the seedlings to emerge, although these difference were not statistically

significant at $P < 0.05$ (Table 15). The untreated infected treatment had a significantly lower number of seedlings emerged and plants alive at harvest than most of the seed treatments. Fewer seedlings emerged in the Maxim 480 FS treatment than in some of the other seed treatments, and the number of seedlings emerged in the former treatment was not significantly different from that in the untreated infected control. There was no seedling death in the untreated uninfected treatment. There were no significant differences in the mean number of leaves per plant 10 days after seedlings or in the total number of tillers at harvest. For growth stage at harvest, there were no significant differences between the untreated infected and untreated uninfected control, or between the untreated infected control and most of the seed treatments. However, some of the seed treatments (Raxil T and Vitaflo 280) had a significantly lower growth stage than the controls, and the growth stage in the Charter 2.5 treatment was not significantly different from that of most seed treatments. There were also more dead seedlings in the same three seed treatments than in the untreated infected controls.

Dark discoloration of subcrown internodes, crowns, and stems was observed in all treatments (Table 16). Mean percent discoloration of subcrown internodes and crowns, and discoloration up the stem were lowest for the untreated uninfected control, although the difference for subcrown internodes was statistically significant at $P < 0.10$). Discoloration of subcrown internodes in the Bayer1 treatment, and of crowns in the Raxil MD treatment, were not different than for the untreated uninfected control.

Fusarium graminearum was isolated from the subcrown internodes and crowns in all treatments, except for the untreated uninfected control (Table 16). Percent isolation of *F. graminearum* was similar for seed treatments and the untreated infected control. There was no difference among treatments in total *Fusarium* spp. isolated from subcrown internodes, but these were lower in the crowns of the untreated uninfected control than in the rest of the treatments, except for Dividend XL and Bayer1, although this difference was only significant at $P < 0.10$. Fungi commonly found in subcrown internodes in the field trials, such as *F. acuminatum*, *F. avenaceum*, *F. equiseti* and *M. bolleyi*, were isolated only occasionally in the controlled-environment trial (data not presented).

Alternaria spp., common soil saprophytes, were isolated from subcrown internodes at higher levels (mean of 0.3%) than from crowns (mean of 0.1%).

Fusarium graminearum was isolated from most of the dead seedlings that were still intact and large enough to plate on agar for fungal identification. Perithecia also formed on the dead plant tissue after incubation.

DISCUSSION

The field trials were conducted at various locations that differed in soil type and under different environmental conditions. In addition, the seed lots used each year were from various crops which had also been grown under different conditions the previous year, and varied in percent infection by *F. graminearum* and percent germination.

The high number of seedlings or spikes per m² in 2005 should be attributed to the more favourable weather conditions. The dry conditions in 2003 at Indian Head/Sintaluta were reflected in lower grain yields at those locations. The higher CRR severity in 2005 than in the previous two years should be also mostly attributed to the wetter conditions in the spring of 2005.

The seed lots used for this study showed lower percent germination *in vitro* than the untreated uninfected seed lots used as control. Seed lots of barley, durum and common wheat with FDK exhibited higher levels of pre-emergence death, post-emergence seedling blight and/or root and crown rot than the uninfected seed lot, although this was not observed every year and was most apparent in the controlled-environment study. Under more favourable conditions for plant growth, there was a greater emergence in 2005 in common wheat in the untreated uninfected control than the untreated infected control which had a higher percentage FDK than any of the other seed lots used that year or in previous years. This agrees with Duthie and Hall (1987), Jones (1999), and Wong et al. (1992) for wheat. No similar reports were found for barley. In *in vitro* tests, Martin and Johnston (1985) reported that germination and vigour of *Fusarium*-infected seeds of barley were higher than for wheat. There were also more spikes per plant of common wheat in the untreated infected control than in the rest of the treatments. There were no differences in grain yield among treatments in 2003 or 2004, and few differences in 2005.

Because of the relatively low levels of *Fusarium* infection in most of the seed lots used in this study and the likely presence of *Fusarium* pathogens in the soil in the locations where these tests were conducted, sampling for disease and fungal isolations was done at early stages of plant growth

in order to provide a reasonable assurance that most plant infections would have originated primarily from seed inoculum and not soil-borne inoculum. In all cases, plants in the untreated uninfected control had a lower level of subcrown internode discoloration than those in the untreated infected control, although this was not always statistically significant. The absence or very low levels of *F. graminearum* in the untreated uninfected control in all three years of the study attested that the presence of this pathogen in the other treatments resulted primarily from seed-borne infections. However, due to the variability among replicates, and/or the low levels of this pathogen in the other treatments including the untreated infected control, differences in levels of *F. graminearum* among treatments were not always significant. For some of the years, this could also be attributed to less than suitable environmental conditions for growth of this pathogen, such as low precipitation in 2003 and low temperatures in 2004. On the other hand, the similar percent isolation of the other commonly isolated *Fusarium* spp., many of which are considered weak pathogens or saprophytes, and of *C. sativus* from the untreated infected and uninfected controls suggests that infections of subcrown internodes by these fungal infections were primarily soil-borne. A very low levels of other *Fusarium* spp. were isolated from the seed lots used in this study.

Seedling emergence of common wheat in 2005 in the seed treatments was also higher in most of the seed treatments than in the untreated infected control. However, treating *Fusarium*-infected seed with fungicides commercially available in Canada did not consistently affect seedling emergence, grain yield or other growth parameters in any of the plant species tested in the field. In addition, chemical seed treatment did not consistently reduce subcrown internode discoloration. For each year, there seemed to be considerable variation among locations and plant species in differences in subcrown internode discoloration between the untreated infected control and the chemical seed treatments.

None of the chemical seed treatments tested appeared to prevent or consistently reduce the growth of *F. graminearum* from barley, durum or common wheat seed into underground plant tissue. *Fusarium graminearum* was recovered from discolored subcrown internodes of all infected treatments, regardless of whether they were treated or not with chemical fungicides. In addition, the

percent isolation of *F. graminearum* and other *Fusarium* spp. from the seed treatments was in general not significantly different than from the untreated infected control.

In regards to *C. sativus*, the most commonly isolated cereal pathogen in Saskatchewan (Fernandez and Jefferson, 2004; Fernandez et al., 2007a, 2007b), in 2003 at Indian Head/Sintaluta and in 2005 at Redvers, there were lower levels of this pathogen in the Dividend XL RTA treatment than in most of the other chemical seed treatment and controls. However, a similar effect of this treatment on *C. sativus* was not observed in 2004 when overall relative levels of this pathogen were higher and closer to what is normally observed in barley and wheat sampled later in the season (Fernandez et al., 2007a, 2007b).

Percent isolation of *M. bolleyi*, a weak pathogen of cereals often isolated together with *C. sativus* (Fernandez et al., 2007a, 2007b), did not differ among chemical seed treatments, or between these and the untreated controls, or differences among years and/or locations were not consistent.

Our results agree with those of others who examined the effectiveness of seed treatments in controlling seed to plant transmission of *Fusarium* infections and improvement of seedling emergence. Duthie and Hall (1985) reported that *F. graminearum*-infected winter wheat seed treated with Vitaflo 280 (carbathiin 14.9%, thiram 13.3%=0.52 g a.i. kg⁻¹ seed) did not have an effect on the incidence of crown infections or result in a significant improvement of emergence in trials in Ontario. Although the emergence of plants grown from infected seed was higher when seed was treated with fungicides, this difference was not statistically significant. Also in Ontario, Jones (1999) showed that triazole fungicides were not as effective as seed treatments with other chemistries in improving stands of *Fusarium*-damaged spring wheat seeds.

In Minnesota, Wiersma and Kandel (2004) reported that when *F. graminearum*-infected hard red spring seed was treated with Vitavax Extra RTU (16.7% carboxin, 1.2% imazalil, 1.5% thiabendazole), or Dividend XL (16.5% difenoconazole and 1.38% mefenoxam), initial plant population, grain yield and test weight did not differ between fungicide treatments and the untreated

control. In Ontario, Schaafsma and Tamburic-Ilincic (2000) reported that *Fusarium*-infected winter wheat seed treated with products that included most of the fungicides used in our study, did not result in significant increases in emergence, number of tillers in the spring or grain yield at either of two locations. Schaafsma et al. (2001) also reported no effect of seed treatments similar to the ones we used in our study on emergence, number of tillers or yield of a heavily-*F. graminearum*-infected winter wheat lot.

However, there are also other previous reports which show positive effects of seed treatments similar to the ones used in our study on plant emergence and yield of *Fusarium*-infected seed lots. Schaafsma and Tamburic-Ilincic (2005) reported that when *Fusarium*-infected winter wheat seed were treated with similar treatments as ours and seeded at different rates, there were more emerged plants than in the untreated plots. Treating seeds with Vitaflo 280 resulted in the greatest emergence. Among the treatments that were similar to ours, the density of spikes was higher only in the Vitaflo 280 treatment than in the untreated control. However, most treatments tested, with the exception of Raxil, increased the number of tillers and resulted in higher grain yields of winter wheat than in the untreated control.

There are also inconsistencies of results among other studies done mostly with soil-borne *Fusarium* inoculum. In Ontario, Celetti and Hall (1987) reported that none of the systemic seed treatments used, some of which (Vitaflo 250) were similar to ours, were effective in reducing *Fusarium* infections of winter wheat crowns, most of which were soil-borne. In their study, *F. avenaceum* was the most abundant species isolated from lesioned crowns of winter wheat plants derived from infected seed, whereas *F. graminearum* and *F. culmorum* occurred less commonly. Sturz and Johnston (1985) reported that Vitavax (carbathiin 26.7%, thiram 38.8%; 50g product/kg seed) did not affect infection of spring wheat crowns by soil-borne *Fusarium* in trials in Prince Edward Island. Although an effect on emergence of barley was observed, there was no effect on vigour, spikes per m², kernel weight or yield.

Gonzalez and Trevathan (2001) reported that Raxil-Thiram 40F improved the seedling stand of

soft red winter wheat over the untreated control in one of the two years of their study in Mississippi. Seedling disease severity in crowns and roots was also lower at 20 days after seeding. Among the fungi isolated from crowns and roots were *C. sativus*, *Fusarium* spp. (the most common being *F. equiseti*, *F. acuminatum* and *F. oxysporum*) and *M. bolleyi*. Raxil-Thiram reduced *C. sativus* in seedlings 20 days after planting relative to the untreated controls. There was also a significant reduction in *Fusarium* spp. at 40 days after seeding, and of *M. bolleyi* up to 80 days after seeding, while the presence of the latter fungus in treated and untreated plants increased during that time. They also reported that treatment with Raxil-Thiram did not result in significant differences in yield or kernel weight.

When spring wheat seeds were planted with the addition of *Fusarium* inoculum in trials at Prince Edward Island, Martin (2005b) reported that all seed treatments, most of which were the same as the ones used in this study, increased emergence relative to the untreated inoculated control. However, only Dividend XL RTA and Raxil MD increased yield whereas Raxil T FS, Gemini and Vitaflo 280 yielded similar to the untreated control. Under controlled conditions, Lamprecht et al. (1990) reported that carboxin/thiram improved the percent survival of wheat plants inoculated with *F. pseudograminearum* or *F. avenaceum*, and reduced disease caused by *F. pseudograminearum* but not *F. avenaceum*.

Other studies that used similar seed treatments as the ones in our study to examine effects on soil-borne infections by pathogens other than *Fusarium*, or in addition to *Fusarium* spp., reported similar inconsistent results in emergence and/or yield of wheat or barley crops. Clark (1977) reported that of the three seed treatments used, Vitaflo (carbathiin 17.3%+thiram 15.4%) was the most effective in reducing the amount of seedling blight in barley caused by *C. sativus* in one of the three years of the study; whereas at maturity there were no comparable differences in seed yields. In trials at Prince Edward Island that relied on natural soil inoculum, Martin and Matters (2002a) observed that the seed treatments reduced root rot of barley but did not affect emergence, yield or kernel weight, whereas Martin (2005a) reported no impact of seed treatments on emergence or root rot of spring barley, and although all treatments resulted in significant yield increases, they had no effect on

kernel weight. Also in Prince Edward Island, Sterling et al. (1977) reported that in most cases, there was no effect of Vitaflo on yield of barley, but in most cases emergence was improved. For spring wheat, Martin and Matters (2002b) reported that all seed treatments used resulted in a significant reduction of root rot symptoms in spring wheat caused by natural soil inoculum. However, most treatments had similar emergence, yield and kernel weight as the untreated control.

On the other hand, Martin et al. (2004) reported that for uninfected seed lots, although chemical seed treatments similar to the ones used in our study had no significant effect on emergence, several of them had a significant impact on yield of spring wheat in trials at Prince Edward Island. Among them, Vitaflo 280 was consistently effective, resulting in a yield benefit of 16 to 17.5%, for the low to high fungicide rate, respectively.

In our study, no attempt was made to test the *in vitro* germination of the chemically-treated seed since this would not reflect actual germination in the soil. Celetti and Hall (1987) reported that although some seed treatments were toxic to *Fusarium* spp. *in vitro*, they were not effective in the field in Ontario. Similarly, Mihuta-Grimm and Forster (1989) reported that although studies indicated that Vitavax 200 effectively reduced seed-borne *Fusarium* spp. in the lab, there was no difference on the incidence of seed decay and seedling blight of wheat and barley under field conditions in Idaho.

However, other studies have shown that some of the currently used chemical seed treatments were not effective against pathogenic *Fusarium* in *in vitro* tests. Martin and Johnston (1982) reported that seed treatments, including Vitaflo 250 (carbathiin 25.3%) did not improve the germination of *Fusarium*-infected seed or increased seedling weight. The ineffectiveness of Vitaflo 280 in improving the emergence or yield of *Fusarium*-infected winter wheat seed lots was thought to be related to the lack of toxicity of one of its ingredients, carbathiin, to *F. graminearum*, although this chemical was toxic to *F. avenaceum* in *in vitro* tests (Celetti and Hall, 1987). Lamprecht et al. (1983) reported that carboxin/thiram reduced disease in spring wheat caused by *F. pseudograminearum* but not *F. avenaceum* under controlled conditions. On the other hand, the *in*

vitro fungicide efficacy of seed treatments that included Dividend 030 FS and Raxil 515 FS (tebuconazole + thiram) was higher against weakly pathogenic species such as *F. poae* than against the more pathogenic species such as *F. graminearum* (Hudec, 2006).

Results from the controlled-environment study showed that in most cases seed treatments improved the emergence of seedlings but in no case was emergence as good as for the untreated uninfected control. Our results also showed that in most cases, plants derived from *Fusarium*-infected seed that germinated, emerged and survived throughout the early stages of plant growth, whether treated with chemicals or not, grew as well as those from the uninfected seed lot. This supports the conclusions from Duthie and Hall (1987) that seed infection decreased the stand density of winter wheat primarily by reducing seed germination but that there was no relationship between seed infection and tillers per plant.

Furthermore, in most cases, the extent of discoloration in subcrown internodes and crowns, and up the stems, was greater in all seed treatments and untreated infected control than in the untreated uninfected control. None of the seed treatments significantly reduced the transmission of *F. graminearum* from infected seed to tissue of live plants, and this transmission appeared to be greater to crowns than to subcrown internodes.

The greater apparent effectiveness of the chemical seed treatments in improving seedling emergence in the growth chamber study using a soil-less mix than in the field trials could be due to the reduced interactions with potentially antagonistic microflora, or other factors that differ between natural soil and the growing medium used in the growth chamber study, and to differences between field and controlled-environmental conditions. Seed with higher infection levels were also used in the growth chamber study than in the field trials.

Although the field and growth chamber trials could not be easily compared to each other, it would be expected that under field conditions there would be less seedling blight than in a controlled-environment due to cooler temperatures in the field at seeding in the spring than in the growth

chamber study (Duthie and Hall, 1987; Gilbert and Tekauz, 1995; Jones, 1999), in addition to other factors such as moisture levels. Seedling blight incidence in plantings of *Fusarium*-damaged seed was shown to be influenced by soil temperature at and during emergence, and increased as the soil temperature during emergence increased (Jones, 1999).

In addition, in the controlled-environment study it was apparent that some seed treatments had a negative impact on plant growth by somewhat retarding plant development, and increasing post-emergence blight. Some other studies have also reported negative effects of chemical seed treatments on crop performance. Similar to our results from the growth chamber study, Schaafsma and Tamburic-Ilincic (2005) found that Raxil 250 FL resulted in fewer plants and a lower density of tillers and spikes than other treatments in the field, and similar to the untreated control. Martin and Matters (2002b) also reported that the Raxil-Thiram treatment had a lower yield than the untreated control but that there was no difference in kernel weight. In trials in Saskatchewan, Verma (1983) reported that all rates of the chemical seed treatments used reduced emergence of spring wheat slightly, which led to the suggestion that phytotoxicity from seed treatments possibly nullified the anticipated yield increase deriving from disease control.

This study showed reduced seedling emergence attributed to *Fusarium*-infection in common wheat in 2005 when seed infection by *F. graminearum* was higher than in of the other seed lots used, and a general lack of effect of seed infection or chemical seed treatment on grain yield or other growth and quality parameters measured. In 2005, for the common wheat crop derived from a heavily-infected seed lot, the untreated infected control had a greater number of spikes per plant than the untreated uninfected control or any of the chemical seed treatments. In cereal crops, grain yield should not be expected to be directly related to seedling emergence, as tillering may compensate for fewer plants resulting from pre-emergence or post-emergence blight, as shown by the untreated infected control of Superb in 2005. The overall non-significant effect of the seed treatments on grain yield obtained in this study should be related to the ability of cereal crops to compensate for fewer plants by producing more tillers. Thus, improved emergence (due to improved germination and/or vigour) might not result in improved grain yield due to compensation by tillering. Similar

conclusions were reached by Fernandez et al. (1997) in a study on red smudge-infected seed in southern Saskatchewan. Wiersma and Kandel (2004) also argued that the ability of spring wheat to tiller and thus compensate for lower plant populations might explain why when the seeding rate of *F. graminearum*-infected hard red spring seed was adjusted according to the percent germination of the untreated seed, initial plant population was higher, but this did not result in a difference in grain yield, test weight or grain protein content. For likely the same reasons, Celetti and Hall (1987) reported no significant correlations between yield of winter wheat and the incidence of diseased crowns at any sampling date.

However, in years or locations where the growing conditions do not favour tiller development (high temperatures and low precipitation), larger differences in grain yield between infected and non-infected seed lots, or between chemically-treated and untreated seed, might be expected. In our study, the growing season in 2004 and 2005 was quite wet, especially in 2005 for Canora, whereas Indian Head/Sintaluta were drier in 2003 than in the following two years. Overall, temperatures were lower in 2004 than in the other two years. Compensation of reduced emergence by production of more spikes per plant in the untreated infected common wheat in 2005 might not be observed under more adverse conditions for plant growth.

No apparent evidence of toxicity caused by some of the seed treatments in the growth chamber study was observed in the field in any of the years this study was conducted.

This study showed that for the infection levels and percent germination of most of the seed lots used, adjustments in seeding rate appeared to be in general adequate to compensate for any possible stand losses caused by failed germination of *Fusarium*-infected seed based on standard germination tests. However, depending on environmental conditions and/or seed infection levels there could also be further germination losses in the soil and reduced vigour which would cause further reductions in emergence and stands, as shown in 2005. Based on soil moisture levels in the spring and percent *F. graminearum* infection, these further losses should be factored in when an adjustment of seeding rate is made for an infected seed lot. Under favourable conditions, most of the chemical seed

treatments tested in this study might improve stands of heavily-infected lots, but only in some cases treating the infected seed might result in higher grain yields. Vitaflo 280 (high rate) and Bayer1 were the only seed treatments that resulted in an increase in grain yield relative to the untreated infected seed in 2005 but not in any of the previous two years.

Based on our observations and those of others, the registered seed treatments currently available in Canada do not seem to be effective in consistently improving the agronomic performance of *Fusarium*-infected barley, common or durum wheat seed lots planted in eastern regions of Saskatchewan. More importantly, treating *F. graminearum*-infected seed with currently registered fungicides will not likely prevent the spread of this pathogen into areas still relatively free of FHB. Thus, cereal producers in western regions of the Canadian Prairies should be strongly encouraged to test their seed lots for the presence of *F. graminearum*, and to plant only uninfected seed.

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LITERATURE CITED

- Canadian Grain Commission. 1998. Official Grain Grading Guide. Winnipeg, MB. 7.1-7.21.
- Celetti, M.J. and R. Hall, 1987. Effects of maneb, carbathiin and triadimenol as seed treatments on yield of winter wheat and on infection of the crown by *Fusarium* spp. *Phytoprotection* 68: 49-55.
- Chinn, S.H.F., 1978. Influence of seed treatment with imazalil on common root rot and the size of the subcrown internode of wheat. *Phytopathology* 68: 1662-1666.
- Chongo, G., Gossen, B.D., Kutcher, H.R., Gilbert, J., Turkington, T.K., Fernandez, M.R., and D. McLaren. 2001. Reaction of seedling roots of 14 crop species to *Fusarium graminearum* from wheat heads. *Can. J. Plant Pathol.* 23: 132-137.
- Clark, R.V., 1977. Field tests of cereal seed treated with nonmercurial fungicides. *Can. Plant Dis. Surv.* 57: 45-48.
- Duthie, J.A., and R. Hall. 1985. Effect of Vitaflo 280 and seed-borne inoculum on crown infections of winter wheat caused by *Fusarium graminearum*. Pesticide Research Report 1985. Expert Committee for Pesticide Use in Agriculture. Ottawa, p.351.
- Duthie, J.A., and R. Hall. 1987. Transmission of *Fusarium graminearum* from seed to stems of winter wheat. *Plant Pathol.* 36: 33-37.
- Environment Canada, 2007. Climate archive. http://www.climate.weatheroffice.ec.gc.ca/climateData/monthlydata_e.html
- Fernandez, M.R. 2007. *Fusarium* populations in roots of oilseed and pulse crops grown in eastern Saskatchewan. *Can. J. Plant Sci.* ("in press").
- Fernandez, M.R., P. Basnyat, and R.P. Zentner. 2007a. Response of wheat root pathogens to crop management in eastern Saskatchewan. *Can. J. Plant Sci.* ("in press").

- Fernandez, M.R., and Y. Chen. 2005. Pathogenicity of *Fusarium* species on different plant parts of spring wheat under controlled conditions. *Plant Dis.* 89:164-169.
- Fernandez, M.R. 2001. Pathogenicity of *F. graminearum* and *F. pseudograminearum* isolates from different sources on common and durum wheat. Pp.119. In: Proceedings of Second Canadian Workshop on Fusarium Head Blight, November 2001, Ottawa, Ontario.
- Fernandez, M.R., Clarke, J.M., DePauw, R.M., and Lefkovitch, L.P., 1997. Emergence and growth of durum wheat derived from red smudge-infected seed. *Crop Sci.* 37:510-514.
- Fernandez, M.R., and P.G. Jefferson. 2004. Fungal populations in roots and crowns of common and durum wheat in Saskatchewan. *Can. J. Plant Pathol.* 26:325-334.
- Fernandez, M.R., F. Selles, D. Gehl, R.M. DePauw, and R.P. Zentner. 2005. Crop production factors associated with Fusarium head blight in spring wheat in eastern Saskatchewan. *Crop Sci.* 45:1908-1916.
- Fernandez, M.R., R.P. Zentner, R.M. DePauw, D. Gehl, and F.C. Stevenson. 2007. Impacts of crop production factors on common root rot of barley and associated fungi in eastern Saskatchewan, Canada. *Crop Sci.* ("in press").
- Fernandez, M.R., R.P. Zentner, R.M. DePauw, D. Gehl, and F.C. Stevenson. 2007c. Impacts of crop production factors on Fusarium head blight in barley in eastern Saskatchewan, Canada. *Crop Sci.* ("in press").
- Gilbert, J., R. Conner, M.R. Fernandez, D. McLaren, S.M. Woods. 2003. Role of *Fusarium graminearum*-infected seed in spread and development of fusarium head blight (FHB) and effects on agronomic performance. *Can. J. Plant Pathol.* 25:73-81.
- Gilbert, J., and A. Tekauz, 1995. Effects of Fusarium head blight and seed treatment on germination, emergence, and seedling vigour of spring wheat. *Can. J. Plant Pathol.* 17: 252-259.
- Gilbert, J., and A. Tekauz, 2000. Review: Recent developments in research on fusarium head blight of wheat in Canada. *Can. J. Plant Pathol.* 22: 1-8.

- Gonzalez, M.S. and L.E. Trevathan, 2001. Effect of biological and chemical seed treatment on seedling disease of soft red winter wheat in Mississippi. *Seed Science and Technology* 29(2): 413-427.
- Halfon-Meiri, A., M.M. Kulik, and J.F. Schoen. 1979. Studies on *Gibberella zeae* carried by wheat seeds produced in the Mid-Atlantic region of the United States. *Seed Sci. Technol.* 7: 439-448.
- Hudec, K., 2006. Influence of seed treatment, temperature and origin of inocula on pathogenicity of *Fusarium* species to wheat and barley seedlings. *Cereal Research Communications* 34: 1059-1066.
- Inch, S.A. and J. Gilbert 2003 . Survival of *Gibberella zeae* on *Fusarium*-damaged kernels of spring wheat. *Plant Dis.* 87:282-287.
- Jones, R.K., 1999. Seedling blight development and control in spring wheat damaged by *Fusarium graminearum* Group 2. *Plant Dis.* 83: 1013-1018.
- Klein, T.A. and Burgess, L.W. 1987. Effect of seed treatment on infection of wheat by seedborne inoculum of *Fusarium graminearum* Group 1. *Austral. Plant Pathol.* 16: 79-81.
- Lamprecht, S.C., W.F.O. Marasas, P.S. Knox-Davies, and F.J. Calitz, 1990. Seed treatment and cultivar reaction of annual *Medicago* species and wheat to *Fusarium avenaceum* and *Fusarium graminearum* Gr. 1. *Phytophylactica* 22: 201-208.
- Littell, R. C., Milliken, G. A., Stroup, W. W. and Wolfinger, R. D. 1996. SAS System for Mixed Models. SAS Institute, Cary NC. 656 pp.
- Martin, R.A., 2005a. Efficacy of fungicide seed treatments on control of net blotch and loose smut, and on yield of spring barley, 2005. 2005 PMR Report: 265-266.
- Martin, R.A., 2005b. Efficacy of fungicide seed treatments on control of septoria leaf blotch and fusarium head blight, and on yield of spring wheat, 2005. 2005 PMR Report: 296-207.
- Martin, R.A. and H.W. Johnston, 1982. Effects and control of fusarium diseases of cereal grains in the Atlantic Provinces. *Can. J. Plant Pathol.* 4: 210-216.

Martin, R.A. and R. Matters, 2001. Efficacy of fungicide seed treatments on control of barley diseases and on yield, 2001. 2001 PMR Report: 345-346.

Martin, R.A., and R. Matters, 2002a. Efficacy of fungicide seed treatments on control of root rot and foliar diseases and on yield of barley, 2001. 2002 PMR Report: 386-387.

Martin, R.A., and R. Matters, 2002b. Efficacy of fungicide seed treatments on control of root rot and foliar diseases and on yield of spring wheat, 2001. 2002 PMR Report: 424-425.

Martin, R.A., R. Matters, and C. Fleming, 2004. Efficacy of fungicide seed treatments on control of fusarium head blight, and on yield of wheat; 2004. 2004 PMR Report.

Mihuta-Grimm, L., and Forster, R.L., 1989. Scab of wheat and barley in southern Idaho and evaluation of seed treatments for eradication of *Fusarium* spp. Plant Dis. 73: 769-771.

Pearse, P.G., G. Holzgang, C.N. Weitzel and M.R. Fernandez, 2007a. Fusarium head blight in barley and oat in Saskatchewan in 2006. Can. Pl. Dis. Surv. 87: 61-62.

Pearse, P.G., G. Holzgang, C.N. Weitzel and M.R. Fernandez, 2007b. Fusarium head blight in common and durum wheat in Saskatchewan in 2006, with comments on irrigated corn. Can. Pl. Dis. Surv. 87: 92-93.

SAS Institute, Inc. 2005. The GLIMMIX Procedure. Statistical Analysis Systems Institute, Inc., Cary, NC. 256 pp.

Saskatchewan Agriculture and Food. 2006. 2006 guide to crop protection. Saskatchewan Agriculture and Food, SK.

Schaafsma, A.W., T. Phibbs, D. Paul, and L. Tamburic-Ilincic, 2001. Seed treatments to control Fusarium head blight in winter wheat. 2001 PMR Report: 366-367.

Schaafsma, A.W. and L. Tamburic-Ilincic, 2000. Seed treatments to control fusarium seedling blight in winter wheat. 2000 PMR Report: 323-324.

- Schaafsma, A.W. and L. Tamburic-Ilincic, 2005. Effect of seeding rate and seed treatment fungicides on agronomic performance, *Fusarium* head blight symptoms, and DON accumulation in two winter wheats. *Plant Dis.* 89: 1109-1113.
- Sterling, J.D.E., H.W. Johnston, and D.C. Munro, 1977. Effects of seed source and seed treatment on barley emergence, yield, and kernel weight. *Can. J. Plant Sci.* 57: 251-256.
- Sturz, A.V. and Johnston, H.W. 1985. Characterization of *Fusarium* colonization of spring barley and wheat produced on stubble or fallow soil. *Can. J. Plant Pathol.* 7: 270-276.
- Sutton, J.C. 1982. Epidemiology of wheat head blight and maize ear rot caused by *Fusarium graminearum*. *Can. J. Plant Pathol.* 4: 195-209.
- Verma, P.R., 1983. Effect of triadimenol, imazalil and nuarimol seed treatment on common root rot and grain yields in spring wheat. *Can. J. Plant Pathol.* 5: 174-176.
- Verma, P.R., D.T. Spurr and F.S. Sedun, 1986. Effect of triadimenol, imazalil and nuarimol seed treatment on subcrown internode length, coleoptile-node-tillering and common root rot in spring wheat. *Plant and Soil* 91: 133-138.
- Wiersma, J.J. and H.J. Kandel, 2004. The response of *Fusarium graminearum*-infected seed of hard red spring wheat to Vitavax Extra RTU and Dividend XL seed treatments. *Plant Management Network*.
- Wang, H., M.R. Fernandez, F.R. Clarke, R.M. DePauw, and J.M. Clarke, 2002. Effect of leaf spotting diseases on grain yield and seed traits of wheat in southern Saskatchewan. *Can. J. Plant Sci.* 82: 507-512.
- Wong, L.S.L., Tekauz, A., Leisle, D., Abramson, D., and McKenzie, R.I.H. 1992. Prevalence, distribution, and importance of fusarium head blight in wheat in Manitoba. *Can. J. Plant Pathol.* 14: 233-238.
- Zadoks, J.C., T.T. Chang, and C.F. Konzak. 1974. A decimal code for the growth stages of cereals. *Weed Res.* 14:415-421.

Table 1. Precipitation and temperature at locations in southern Saskatchewan where field trials were conducted , from 2003 to 2005.

| Year/location | Precipitation (mm) | | | | | | Temperature (°C) | | | | | |
|-----------------------------------|--------------------|-------|-------|-------|--------|---------------------|------------------|------|------|------|----------------------|------|
| | April | May | June | July | August | Total (May-July) | April | May | June | July | August (May-July) | Mean |
| <u>2003</u> | | | | | | | | | | | | |
| Indian Head/Sintaluta | 61.6 | 23.6 | 18.0 | 23.4 | 10.6 | 65.0 | 4.3 | 11.4 | 15.5 | 18.6 | 19.5 | 15.2 |
| <u>2004</u> | | | | | | | | | | | | |
| Canora | 9.8 | 100.4 | 79.6 | 83.9 | 95.1 | 263.9 | 4.4 | 6.7 | 12.9 | 17.1 | 13.9 | 12.2 |
| Indian Head/Sintaluta | 17.1 | 104.8 | 85.0 | 75.4 | 71.2 | 265.2 | 3.7 | 6.8 | 12.6 | 16.3 | 13.1 | 11.9 |
| Redvers | 21.4 | 143.2 | 67.2 | 72.8 | 51.6 | 283.2 | 4.5 | 7.5 | 13.6 | 17.4 | 14.0 | 12.8 |
| <u>2005</u> | | | | | | | | | | | | |
| Canora | 9.4 | 88.2 | 159.2 | 115.6 | 164.0 | 363.0 | 6.0 | 9.4 | 15.4 | 18.4 | 16.1 | 14.4 |
| Indian Head/Sintaluta | 6.8 | 57.6 | 99.2 | 59.2 | 98.0 | 216.0 | 5.5 | 8.7 | 14.8 | 16.9 | 15.6 | 13.5 |
| Redvers | 6.2 | 83.3 | 148.4 | 44.4 | 22.6 | 276.1 | 7.0 | 9.9 | 16.4 | 18.8 | 16.6 | 15.0 |
| <u>Long term mean (1971-2000)</u> | | | | | | | | | | | | |
| Canora | 25.3 | 50.6 | 85.8 | 73.1 | 59.0 | 209.5 | 2.6 | 10.8 | 15.4 | 17.6 | 16.6 | 14.6 |
| Indian Head/Sintaluta | 24.6 | 55.7 | 78.9 | 67.1 | 52.7 | 201.7 | 4.0 | 11.4 | 16.1 | 18.4 | 17.5 | 15.3 |
| Redvers | na | na | na | na | na | na | na | na | na | na | na | na |

Weather data for the Canora site was obtained from Good Spirit Lake
na: not available

Table 2. Field trials conducted at various locations in Saskatchewan from 2003 to 2005, percent germination and percent isolation of *F. graminearum* from untreated infected seed of the barley, durum and common wheat seed lots used.

| Year/cultivar | Crop species | Location of field trials | Percent germination | Percent seed infected by <i>F. graminearum</i> |
|----------------------|---------------------|---|----------------------------|---|
| 2003 | | | | |
| Kyle | durum wheat | Indian Head, Sintaluta | 68 | 42 |
| Superb | common wheat | Indian Head, Sintaluta | 86 | 34 |
| 2004 | | | | |
| Excel | barley | Indian Head, Sintaluta, Redvers, Canora | 74 | 5 |
| Avonlea | durum wheat | Canora, Redvers | 48 | 9 |
| Navigator | durum wheat | Indian Head, Sintaluta | 81 | 10 |
| Prodigy | common wheat | Indian Head, Sintaluta, Redvers, Canora | 70 | 21 |
| 2005 | | | | |
| Westeck | barley | Indian Head, Redvers, Canora | 80 | 7 |
| Superb | common wheat | Indian Head, Redvers, Canora | 59 | 63 |

Table 3. Chemical seed treatments used in field trials conducted in southern Saskatchewan, from 2003 to 2005, and in growth chamber trials.

| Product name | Active ingredients and rates | Company | Years tested in field | Growth chamber |
|--------------------------------|---|----------|-----------------------|----------------|
| Charter 2.5 | triticonazol. (2.5g) | BASF | 2003, 2004, 2005 | yes |
| Dividend XL RTA | difenoconazole (12g) and metalaxyl-M (1g) | Syngenta | 2003, 2004, 2005 | yes |
| Gemini | thiram 50gai/100kg + triticonazole 5gai/100kg | BASF | 2003, 2004, 2005 | yes |
| JAU | prothioconazole 5gai/100kg | Bayer | 2003 | no |
| JAU + Raxil 250 | prothioconazole 5gai/100kg + tebuconazole 0.75gai/100kg | Bayer | 2003 | no |
| Maxim 480 FS | fludioxonil 2.2 gai/100kg | BASF | 2004, 2005 | yes |
| Raxil 250 + Trilex FL | tebuconazole 1.5gai/100kg + trifloxystrobin 5gai/100kg | Bayer | 2003 | no |
| Raxil 250 FL | tebuconazole (1.5g) | Bayer | 2003, 2004, 2005 | no |
| Raxil MD | tebuconazole 1.5gai/100kg + metalaxyl 2gai/100kg | Bayer | 2004, 2005 | yes |
| Raxil T | tebuconazole 1.5gai/100kg + thiram 50gai/100kg | Bayer | 2003, 2004, 2005 | yes |
| VitaFlo 280 (230mL, low rate) | carbathiin (39g) and thiram (35g) | Bayer | 2004, 2005 | no |
| VitaFlo 280 (330mL, high rate) | carbathiin (56g) and thiram (50g) | Bayer | 2003, 2004, 2005 | yes |
| BASF1 | experimental product | BASF | 2003 | no |
| BASF2 | experimental product | BASF | 2003 | no |
| BASF3 | experimental product | BASF | 2004, 2005 | no |
| BASF4 | experimental product | BASF | 2004, 2005 | no |
| Bayer1 | experimental product | Bayer | 2004, 2005 | yes |

Table 4. Overall means of agronomic, disease and fungal data collected in field trials conducted in southern Saskatchewan, from 2003 to 2005.

| Year | seedlings per m ² | days to heading | spikes per m ² | spikes per plant | kernels per spike | kernels per m ² | plant height (cm) | grain yield (kg ha ⁻¹) | kernel weight (g) | test weight (g) | protein |
|------|---------------------------------|--------------------|------------------------------|---------------------|----------------------|-------------------------------|-------------------------|--|-------------------------|-----------------------|---------|
| 2003 | 161.6 | | 405.4 | 2.6 | 21.7 | 8500 | 80.4 | 2822 | 33.5 | 381.6 | 14.8 |
| 2004 | 157.6 | 62.5 | 404.0 | 3.1 | 31.3 | 11934 | 88.0 | 4141 | 35.0 | 336.6 | |
| 2005 | 206.4 | 56.5 | 553.5 | 2.8 | 20.1 | 9992 | 83.6 | 3908 | 39.0 | 342.4 | |

| Year | CRR23 | CRR3 | Cs | Total <i>Fus</i> spp. | <i>Facu</i> | <i>Fav</i> | <i>Fc</i> | <i>Fe</i> | <i>Fg</i> | <i>Foxy</i> | <i>Mb</i> | <i>Alt</i> |
|----------------------|-------|------|------|--------------------------|-------------|------------|-----------|-----------|-----------|-------------|-----------|------------|
| Percentage isolation | | | | | | | | | | | | |
| 2003 | 12.1 | 4.5 | 12.9 | 50.5 | 8.3 | 2.8 | 1.6 | 9.9 | 10.3 | 2.0 | 10.8 | 13.6 |
| 2004 | 9.3 | 5.0 | 40.6 | 12.8 | 2.8 | 0.4 | 0.5 | 2.0 | 1.2 | 1.8 | 4.8 | 13.7 |
| 2005 | 38.8 | 5.0 | 20.0 | 27.2 | 1.2 | 4.0 | 0.6 | 4.1 | 3.9 | 2.9 | 1.0 | 13.5 |

CRR23: percentage of plants with severe or moderately severe discoloration on the subcrown internode; CRR3: percentage of plants with severe discoloration in the subcrown internode.

Alt: *Alternaria* spp.; *Cs*: *Cochliobolus sativus*; *Fus* spp.: total *Fusarium* spp.; *Facu*: *F. acuminatum*; *Fav*: *F. avenaceum*; *Fc*: *F. culmorum*; *Fe*: *F. equiseti*; *Fg*: *F. graminearum*; *Foxy*: *F. oxysporum*; *Mb*: *Microdochium bolleyi*.

Table 5. Effect of location, plant species and chemical seed treatment on emergence, growth, grain yield and quality of plants derived from *Fusarium* -infected seed planted in field trials in Saskatchewan in 2003.

| Effect | seedlings per m ² | | spikes per m ² | | spikes per plant | | kernels per spike | | kernels per m ² | | plant height (cm) | | grain yield (kg ha-1) | | kernel weight (g) | | test weight (g) | | protein | |
|---------------------------------------|---------------------------------|----|------------------------------|-----|---------------------|------|----------------------|------|-------------------------------|------|-------------------------|------|-----------------------------|------|-------------------------|-------|-----------------------|------|---------|--|
| P value | | | | | | | | | | | | | | | | | | | | |
| location | <.0001 | | 0.000 | | 0.193 | | 0.122 | | 0.201 | | <.0001 | | 0.296 | | <.0001 | | <.0001 | | 0.014 | |
| plant species | 0.518 | | <.0001 | | <.0001 | | <.0001 | | 0.024 | | <.0001 | | <.0001 | | <.0001 | | <.0001 | | <.0001 | |
| seed treatment | <.0001 | | 0.527 | | 0.011 | | 0.677 | | 0.121 | | 0.027 | | 0.205 | | 0.714 | | 0.758 | | 0.627 | |
| location*plant species | 0.625 | | <.0001 | | 0.099 | | 0.227 | | <.0001 | | 0.002 | | <.0001 | | <.0001 | | <.0001 | | <.0001 | |
| location*seed treatment | 0.218 | | 0.840 | | 0.991 | | 0.997 | | 0.787 | | 0.752 | | 0.869 | | 0.850 | | 0.429 | | 0.891 | |
| plant species*seed treatment | 0.094 | | 0.742 | | 0.897 | | 0.282 | | 0.597 | | 0.277 | | 0.388 | | 0.496 | | 0.614 | | 0.077 | |
| location*plant species*seed treatment | 0.208 | | 0.863 | | 0.255 | | 0.366 | | 0.582 | | 0.841 | | 0.701 | | 0.436 | | 0.184 | | 0.351 | |
| Mean | | | | | | | | | | | | | | | | | | | | |
| Location | | | | | | | | | | | | | | | | | | | | |
| Indian Head | 135.6 | b | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | |
| Sintaluta | 187.6 | a | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | . | |
| Plant species | | | | | | | | | | | | | | | | | | | | |
| durum wheat | . | . | . | 2.3 | b | 23.4 | a | . | . | . | . | . | . | . | . | . | . | . | . | |
| common wheat | . | . | . | 2.8 | a | 20.1 | b | . | . | . | . | . | . | . | . | . | . | . | . | |
| Location*plant species | | | | | | | | | | | | | | | | | | | | |
| Indian Head: | | | | | | | | | | | | | | | | | | | | |
| durum wheat | | | 326.3 | c | | | | 8164 | ab | 77.5 | c | 3442 | a | 42.3 | a | 390.1 | a | 14.3 | b | |
| common wheat | | | 370.3 | b | | | | 7815 | b | 66.2 | d | 2488 | b | 31.9 | b | 388.6 | a | 15.8 | a | |
| Sintaluta: | | | | | | | | | | | | | | | | | | | | |
| durum wheat | | | 403.7 | b | | | | 8488 | b | 96.6 | a | 2706 | b | 31.9 | b | 380.8 | b | 14.3 | b | |
| common wheat | | | 521.3 | a | | | | 9530 | a | 81.4 | b | 2652 | b | 27.9 | c | 367.1 | c | 14.7 | b | |
| Seed treatment | | | | | | | | | | | | | | | | | | | | |
| Charter 2.5 | 177.0 | ab | . | 2.4 | ab | . | . | . | | 80.6 | ab | . | . | . | . | . | . | . | . | |
| Dividend XL RTA | 173.5 | ab | . | 2.4 | b | . | . | . | . | 78.4 | ab | . | . | . | . | . | . | . | . | |
| Gemini | 162.7 | ab | . | 2.5 | ab | . | . | . | . | 82.9 | a | . | . | . | . | . | . | . | . | |
| JAU | 181.9 | a | . | 2.4 | ab | . | . | . | . | 81.6 | ab | . | . | . | . | . | . | . | . | |
| JAU+Raxil250 | 161.6 | ab | . | 2.4 | b | . | . | . | . | 79.8 | ab | . | . | . | . | . | . | . | . | |

| | | | | | | | | | | | | | |
|----------------------|-------|----|---|-----|----|---|---|------|----|---|---|---|---|
| Raxil 250 FL | 162.6 | ab | . | 2.6 | ab | . | . | 81.4 | ab | . | . | . | . |
| Raxil 250+Trilex FL | 157.8 | ab | . | 2.6 | ab | . | . | 80.8 | ab | . | . | . | . |
| Raxil T | 167.5 | ab | . | 2.6 | ab | . | . | 80.2 | ab | . | . | . | . |
| Vitaflo 280 (high) | 156.1 | ab | . | 2.8 | ab | . | . | 79.5 | ab | . | . | . | . |
| BASF1 | 151.5 | ab | . | 2.6 | ab | . | . | 82.4 | a | . | . | . | . |
| BASF2 | 168.9 | ab | . | 2.4 | b | . | . | 81.0 | ab | . | . | . | . |
| Untreated infected | 149.5 | bc | . | 2.8 | ab | . | . | 80.3 | ab | . | . | . | . |
| Untreated uninfected | 130.3 | c | . | 3.1 | a | . | . | 76.8 | b | . | . | . | . |

Means in a column for an effect or an interaction followed by the same letter are not significantly different ($P < 0.05$).

Table 6. Effect of location, plant species and chemical seed treatment on emergence, growth, yield and quality of plants derived from *Fusarium* -infected seed planted in field trials in Saskatchewan in 2004.

| Effect | seedlings per m ² | days to heading | spikes per m ² | spikes per plant | kernels per spike | kernels per m ² | plant height (cm) | grain yield (kg ha-1) | kernel weight (g) | test weight (g) |
|---------------------------------------|---------------------------------|--------------------|------------------------------|---------------------|----------------------|-------------------------------|-------------------------|-----------------------------|-------------------------|-----------------------|
| P value | | | | | | | | | | |
| location | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 |
| plant species | <.0001 | 0.000 | 0.000 | 0.001 | 0.001 | 0.002 | <.0001 | 0.002 | <.0001 | <.0001 |
| seed treatment | 0.224 | 0.753 | 0.694 | 0.716 | 0.807 | 0.658 | 0.797 | 0.682 | 0.207 | 0.757 |
| location*plant species | <.0001 | <.0001 | 0.085 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 |
| location*seed treatment | 0.604 | 0.993 | 0.879 | 0.767 | 0.984 | 0.923 | 0.793 | 0.872 | 0.414 | 0.294 |
| plant species*seed treatment | 0.003 | 0.852 | 0.861 | 0.676 | 0.655 | 0.404 | 0.752 | 0.220 | 0.512 | 0.613 |
| location*plant species*seed treatment | 0.505 | 1.000 | 0.994 | 0.634 | 0.994 | 0.876 | 0.644 | 0.991 | 0.134 | 0.645 |
| Means | | | | | | | | | | |
| Location | | | | | | | | | | |
| Canora | . | . | 490 a | . | . | . | . | . | . | . |
| Indian Head | . | . | 421 b | . | . | . | . | . | . | . |
| Santaluta | . | . | 302 c | . | . | . | . | . | . | . |
| Plant species | | | | | | | | | | |
| barley | . | . | 353 c | . | . | . | . | . | . | . |
| durum wheat | . | . | 404 b | . | . | . | . | . | . | . |
| common wheat | . | . | 454 a | . | . | . | . | . | . | . |
| Location*plant species | | | | | | | | | | |
| Barley: | | | | | | | | | | |
| Canora | 160.7 c | 57.8 d | | 2.8 c | 29.2 cd | 12073 b | 74.9 f | 4406 b | 36.8 c | 303.7 e |
| Indian Head | 107.8 de | 63.0 c | | 3.6 b | 33.6 bc | 12430 ab | 86.1 d | 4857 a | 39.3 b | 316.2 d |
| Santaluta | 50.0 f | 69.5 a | | 5.6 a | 47.1 a | 11316 b | 74.8 f | 4014 c | 35.9 c | 263.0 f |
| Durum wheat: | | | | | | | | | | |
| Canora | 261.9 a | 57.0 e | | 2.0 c | 24.2 de | 12005 b | 91.7 c | 5054 a | 42.3 a | 386.5 a |
| Indian Head | 158.9 c | 63.0 c | | 2.7 c | 29.4 cd | 11734 b | 88.5 d | 4723 ab | 40.7 ab | 362.7 b |
| Santaluta | 86.0 e | 66.0 b | | 4.0 b | 29.0 cd | 8661 c | 78.0 e | 2835 e | 32.8 d | 313.5 de |
| Common wheat: | | | | | | | | | | |
| Canora | 233.2 ab | 57.0 e | | 2.3 c | 24.9 d | 13624 a | 96.6 b | 4815 a | 35.4 c | 391.7 a |

| | | | | | | | | | | | | | | | | | | |
|-------------|-------|----|------|---|-----|---|------|----|-------|----|-------|---|------|---|------|---|-------|---|
| Indian Head | 223.4 | b | 63.0 | c | 2.2 | c | 27.8 | cd | 13192 | ab | 105.0 | a | 3601 | d | 27.9 | e | 359.4 | b |
| Sintaluta | 136.4 | cd | 66.0 | b | 2.7 | c | 36.2 | b | 12368 | b | 96.3 | b | 2962 | e | 24.0 | f | 332.5 | c |

Plant species*seed treatment

| Seed treatment | Common wheat | |
|-----------------------|---------------------|-----|
| Charter 2.5 | 260.2 | a |
| Dividend XL RTA | 244.9 | ab |
| Gemini | 227.6 | ab |
| Maxim 480 FS | 231.9 | a-c |
| Raxil 250 FL | 203.6 | a-c |
| Raxil MD | 203.0 | a-c |
| Raxil T | 259.0 | ab |
| VitaFlo 280 (low) | 253.5 | ab |
| VitaFlo 280 (high) | 243.6 | ab |
| BASF3 | 213.5 | a-c |
| BASF4 | 223.9 | a-c |
| Bayer I | 220.2 | a-c |
| Untreated infected | 185.2 | bc |
| Untreated uninfected | 158.1 | c |

Means in a column for an effect or an interaction followed by the same letter are not significantly different ($P < 0.05$).

Table 7. Effect of location, plant species and chemical seed treatment on emergence, growth, grain yield and quality of plants derived from *Fusarium* -infected seed planted in field trials in Saskatchewan in 2005.

| Effect | seedlings per m ² | days to heading | spikes per m ² | spikes per plant | kernels per spike | kernels per m ² | plant height (cm) | grain yield (kg ha-1) | kernel weight (g) | test weight (g) |
|---------------------------------------|---------------------------------|--------------------|------------------------------|---------------------|----------------------|-------------------------------|-------------------------|-----------------------------|-------------------------|-----------------------|
| P value | | | | | | | | | | |
| location | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 0.053 | <.0001 | <.0001 | <.0001 | <.0001 |
| plant species | 0.062 | 0.931 | <.0001 | <.0001 | <.0001 | 0.002 | 0.001 | <.0001 | 0.001 | <.0001 |
| seed treatment | <.0001 | 0.904 | 0.190 | 0.001 | 0.711 | 0.001 | 0.021 | 0.001 | 0.967 | 0.123 |
| location*plant species | <.0001 | <.0001 | 0.001 | 0.000 | <.0001 | 0.466 | <.0001 | <.0001 | <.0001 | <.0001 |
| location*seed treatment | 0.094 | 0.907 | 0.663 | 0.744 | 0.972 | 0.250 | 0.672 | 0.151 | 0.907 | 0.513 |
| plant species*seed treatment | <.0001 | 0.091 | 0.748 | <.0001 | 0.644 | 0.127 | 0.814 | 0.566 | 0.150 | 0.084 |
| location*plant species*seed treatment | 0.876 | 0.024 | 0.217 | 0.913 | 0.662 | 0.098 | 0.172 | 0.079 | 0.306 | 0.013 |
| Means | | | | | | | | | | |
| Plant species | | | | | | | | | | |
| barley | . | . | . | . | . | 10995 a | . | . | . | . |
| common wheat | . | . | . | . | . | 8988 b | . | . | . | . |
| Seed treatment | | | | | | | | | | |
| Charter 2.5 | . | . | . | . | . | 9826 ab | 82.9 ab | 3826 ab | . | . |
| Dividend XL RTA | . | . | . | . | . | 9818 ab | 82.8 ab | 3871 ab | . | . |
| Gemini | . | . | . | . | . | 10270 ab | 84.5 ab | 4064 ab | . | . |
| Maxim 480 FS | . | . | . | . | . | 9717 ab | 82.8 ab | 3778 ab | . | . |
| Raxil 250 FL | . | . | . | . | . | 9649 ab | 82.8 ab | 3754 ab | . | . |
| Raxil MD | . | . | . | . | . | 10051 ab | 84.0 ab | 3938 ab | . | . |
| Raxil T | . | . | . | . | . | 10156 ab | 84.6 ab | 3938 ab | . | . |
| VitaFlo 280 (low) | . | . | . | . | . | 9602 ab | 82.6 ab | 3742 ab | . | . |
| VitaFlo 280 (high) | . | . | . | . | . | 10369 a | 85.9 a | 4089 a | . | . |
| BASF3 | . | . | . | . | . | 9809 ab | 83.3 ab | 3855 ab | . | . |
| BASF4 | . | . | . | . | . | 10231 ab | 84.1 ab | 3955 ab | . | . |
| Bayer1 | . | . | . | . | . | 10574 a | 82.6 ab | 4164 a | . | . |
| Untreated infected | . | . | . | . | . | 9236 b | 82.2 b | 3638 b | . | . |
| Untreated uninfected | . | . | . | . | . | 10577 a | 84.6 ab | 4095 a | . | . |
| Location*plant species | | | | | | | | | | |
| Barley | | | | | | | | | | |
| Canora | 207.1 b | | 315.8 e | 1.6 d | 35.1 a | | 80.6 c | 4609 b | 42.4 b | |
| Indian Head | 224.1 a | | 542.1 c | 2.5 c | 20.8 b | | 88.3 a | 4835 a | 43.7 a | |
| Redvers | 215.6 ab | | 656.3 b | 3.1 b | 16.8 c | | 75.8 d | 4339 c | 39.5 c | |
| Common wheat | | | | | | | | | | |
| Canora | 160.5 c | | 405.2 d | 2.6 c | 21.8 b | | 84.4 b | 3719 d | 42.7 ab | |
| Indian Head | 224.6 a | | 685.7 ab | 3.2 b | 13.8 d | | 88.1 a | 2879 e | 31.0 c | |

Redvers 206.4 b 715.8 a 3.5 a 12.5 d 84.0 b 3065 e 34.6 d

| <u>Plant species*seed treatment</u> | | | | | | | <u>Canora</u> | | <u>Redvers</u> | | <u>Wheat</u> | | <u>Canora</u> | | <u>Redvers</u> | |
|-------------------------------------|--------------|---------------|--------------|---------------|--------------|--------------|---------------|--------------|----------------|--------------|--------------|--------------|---------------|--------------|----------------|--------------|
| | <u>Wheat</u> | <u>Barley</u> | <u>Wheat</u> | <u>Barley</u> | <u>Wheat</u> | <u>Wheat</u> | <u>Wheat</u> | <u>Wheat</u> | <u>Barley</u> | <u>Wheat</u> | <u>Wheat</u> | <u>Wheat</u> | <u>Wheat</u> | <u>Wheat</u> | <u>Wheat</u> | <u>Wheat</u> |
| Charter 2.5 | 161.0 de | 52.5 a | 54.5 a | 60.8 a | 59.0 a | 3.6 b | | | | | | | 362.3 ab | | 371.4 b | |
| Dividend XL RTA | 221.5 ab | 51.8 a | 54.5 a | 60.8 a | 58.9 a | 2.7 cd | | | | | | | 366.0 ab | | 374.3 ab | |
| Gemini | 198.1 b-d | 52.5 a | 53.8 a | 61.0 a | 59.0 a | 3.2 b-d | | | | | | | 368.8 a | | 378.9 ab | |
| Maxim 480 FS | 216.0 a-c | 52.5 a | 53.8 a | 60.9 a | 59.2 a | 2.8 b-d | | | | | | | 363.0 ab | | 377.9 ab | |
| Raxil 250 FL | 212.0 a-c | 52.5 a | 53.3 a | 61.0 a | 59.1 a | 2.8 b-d | | | | | | | 363.8 ab | | 373.9 ab | |
| Raxil MD | 190.7 b-d | 51.0 a | 53.3 a | 60.9 a | 59.1 a | 3.1 b-d | | | | | | | 368.0 ab | | 373.7 ab | |
| Raxil T | 200.7 bc | 51.8 a | 54.3 a | 61.0 a | 59.1 a | 3.0 b-d | | | | | | | 369.8 ab | | 381.2 a | |
| Vitaflo 280 (low) | 195.1 b-d | 52.5 a | 53.3 a | 60.9 a | 59.2 a | 2.9 b-d | | | | | | | 360.8 ab | | 378.0 ab | |
| Vitaflo 280 (high) | 224.0 ab | 51.8 a | 54.0 a | 60.9 a | 59.1 a | 2.7 cd | | | | | | | 369.8 a | | 379.2 ab | |
| BASF3 | 179.8 cd | 51.0 a | 55.0 a | 60.9 a | 59.2 a | 3.5 bc | | | | | | | 362.5 ab | | 375.0 ab | |
| BASF4 | 190.9 b-d | 51.8 a | 55.5 a | 60.9 a | 59.1 a | 3.2 b-d | | | | | | | 366.8 ab | | 376.9 ab | |
| Bayer1 | 208.5 a-c | 51.0 a | 54.3 a | 61.0 a | 59.0 a | 3.1 b-d | | | | | | | 370.8 a | | 376.8 ab | |
| Untreated infected | 126.6 e | 53.3 a | 53.3 a | 60.8 a | 59.1 a | 4.4 a | | | | | | | 356.0 b | | 370.8 b | |
| Untreated uninfected | 239.1 a | 53.3 a | 52.5 a | 60.4 a | 58.9 a | 2.6 d | | | | | | | 368.5 ab | | 375.2 ab | |

Means in a column for an effect or an interaction followed by the same letter are not significantly different (P<0.05).

Table 8. Effect of location, plant species and chemical seed treatments on common root rot severity in plants derived from *Fusarium* -infected seed planted in field trials conducted in Saskatchewan in 2003.

| Effect | CRR23 | | CRR3 | |
|---------------------------------------|---------|--|---------|--|
| | P value | | | |
| location | 0.073 | | 0.087 | |
| plant species | 0.001 | | 0.052 | |
| seed treatment | < 0.001 | | < 0.001 | |
| location*plant species | 0.883 | | 0.170 | |
| location*seed treatment | 0.079 | | 0.250 | |
| plant species*seed treatment | 0.004 | | 0.008 | |
| location*plant species*seed treatment | 0.126 | | 0.252 | |

| Mean (%) | | | | | |
|------------------------------|-------|----|-------|-----|--|
| Plant species*seed treatment | | | | | |
| Seed treatment | Durum | | Wheat | | |
| Charter 2.5 | 15.9 | ab | 14.8 | a | |
| Dividend XL RTA | 13.0 | ab | 13.4 | a-c | |
| Gemini | 12.2 | ab | 2.9 | e | |
| IAU | 13.7 | ab | 11.9 | a-d | |
| IAU+Raxil 250 | 9.5 | b | 12.7 | a-c | |
| Raxil 250 FL | 10.8 | b | 11.7 | a-d | |
| Raxil 250+Trilex FL | 12.4 | ab | 14.2 | ab | |
| Raxil T | 13.2 | ab | 13.8 | a-c | |
| VitaFlo 280 (high) | 11.8 | ab | 10.7 | a-d | |
| BASF1 | 16.9 | ab | 6.5 | c-e | |
| BASF2 | 11.4 | ab | 4.8 | de | |
| Untreated infected | 20.8 | a | 16.1 | a | |
| Untreated uninfected | 11.9 | ab | 7.0 | b-e | |

CRR23: percentage of plants with severe or moderately severe discoloration on the subcrown internode;

CRR3: percentage of plants with severe discoloration in the subcrown internode.

Means in a column for an effect or an interaction followed by the same letter are not significantly different ($P < 0.05$).

Table 9. Effect of location, plant species and chemical seed treatment on common root rot severity in plants derived from *Fusarium* -infected seed planted in field trials in Saskatchewan in 2004.

| Effect | CRR23 | CRR3 |
|---------------------------------------|----------|---------|
| | P value | |
| location | <.0001 | <.0001 |
| plant species | 0.007 | 0.005 |
| seed treatment | 0.000 | 0.000 |
| location*plant species | <.0001 | <.0001 |
| location*seed treatment | 0.060 | 0.201 |
| plant species*seed treatment | 0.190 | 0.409 |
| location*plant species*seed treatment | 0.975 | 0.916 |
| | Mean (%) | |
| <u>Location*plant species</u> | | |
| Barley | | |
| Canora | 27.9 a | 17.7 a |
| Indian Head | 8.8 b-d | 3.2 de |
| Redvers | 5.2 de | 1.0 e |
| Sintaluta | 13.4 bc | 7.7 bc |
| Durum wheat | | |
| Canora | 12.6 bc | 6.2 b |
| Indian Head | 5.5 de | 2.3 de |
| Redvers | 1.1 e | 0.2 e |
| Sintaluta | 3.4 de | 1.0 e |
| Common wheat | | |
| Canora | 14.9 b | 9.7 b |
| Indian Head | 8.2 c-e | 4.8 cd |
| Redvers | 3.5 de | 1.3 e |
| Sintaluta | 7.4 c-e | 4.5 cd |
| <u>Seed treatment</u> | | |
| Charter 2.5 | 11.8 a | 6.2 ab |
| Dividend XL RTA | 5.3 b | 2.4 c |
| Gemini | 9.9 ab | 5.7 a-c |
| Maxim 480 FS | 8.5 ab | 4.0 bc |
| Raxil 250 FL | 9.1 ab | 5.2 a-c |
| Raxil MD | 10.5 a | 5.4 a-c |
| Raxil T | 10.5 a | 6.0 a-c |
| VitaFlo 280 (low) | 10.5 a | 5.4 a-c |
| VitaFlo 280 (high) | 10.0 ab | 5.5 a-c |
| BASF3 | 7.3 b | 3.7 bc |
| BASF4 | 7.6 ab | 4.1 bc |
| Bayer1 | 8.7 ab | 4.1 bc |
| Untreated infected | 12.4 a | 7.9 a |
| Untreated uninfected | 8.3 ab | 3.9 bc |

CRR23: percentage of plants with severe or moderately severe discoloration on the subcrown internode; CRR3: percentage of plants with severe discoloration in the subcrown internode.

Means in a column for an effect or an interaction followed by the same letter are not significantly different ($P < 0.05$).

Table 10. Effect of location, plant species and chemical seed treatment on common root rot severity in plants derived from *Fusarium*-infected seed planted in field trials in Saskatchewan in 2005.

| Effect | CRR23 | | CRR3 | |
|---------------------------------------|----------|---|--------|----|
| | P value | | | |
| location | <.0001 | | <.0001 | |
| plant species | 0.001 | | <.0001 | |
| seed treatment | 0.218 | | 0.015 | |
| location*plant species | <.0001 | | <.0001 | |
| location*seed treatment | 0.403 | | 0.290 | |
| plant species*seed treatment | 0.934 | | 0.287 | |
| location*plant species*seed treatment | 0.393 | | 0.779 | |
| | Mean (%) | | | |
| <u>Location*Plant species</u> | | | | |
| Barley | | | | |
| Indian Head | 55.7 | b | 3.3 | b |
| Redvers | 62.6 | a | 4.2 | b |
| Common wheat | | | | |
| Indian Head | 8.5 | d | 2.9 | b |
| Redvers | 28.3 | c | 9.5 | a |
| <u>Seed treatment</u> | | | | |
| Charter 2.5 | . | | 5.0 | ab |
| Dividend XL RTA | . | | 3.9 | ab |
| Gemini | . | | 6.0 | ab |
| Maxim 480 FS | . | | 3.9 | ab |
| Raxil 250 FL | . | | 6.7 | a |
| Raxil MD | . | | 6.3 | a |
| Raxil T | . | | 5.0 | ab |
| VitaFlo 280 (low) | . | | 6.3 | ab |
| VitaFlo 280 (high) | . | | 5.3 | ab |
| BASF 3 | . | | 3.7 | ab |
| BASF 4 | . | | 4.9 | ab |
| Bayer 1 | . | | 4.6 | ab |
| Untreated infected | . | | 5.6 | ab |
| Untreated uninfected | . | | 2.3 | b |

CRR23: percentage of plants with severe or moderately severe discoloration on the subcrown internode; CRR3: percentage of plants with severe discoloration in the subcrown internode.

Means in a column for an effect or an interaction followed by the same letter are not significantly different ($P < 0.05$).

Table 11. Effect of location, plant species, seed treatment and their interactions on percent isolation of fungi from subcrown internodes of barley, durum and common wheat in field trials at four locations in southern Saskatchewan, from 2003 to 2005.

| Year/Effect | Fungi | | | | | | | | |
|---------------------------------------|---------------------------------------|-------------------------------|-------------------|------------------|--------------------|--------------------|-----------------------|---------------------|-------------------------------------|
| | <i>Cochliobolus</i> <i>sarivus</i> | Total <i>Fusarium</i> spp. | <i>acuminatum</i> | <i>avenaceum</i> | <i>F. culmorum</i> | <i>F. equiseti</i> | <i>F. graminearum</i> | <i>F. oxysporum</i> | <i>Microdochium</i> <i>bolvi</i> |
| | P value | | | | | | | | |
| 2003 | | | | | | | | | |
| location | < 0.001 | < 0.001 | < 0.001 | < 0.001 | 0.003 | < 0.001 | 0.001 | < 0.001 | 0.438 |
| plant species | 0.765 | 0.061 | < 0.001 | 0.568 | 0.001 | 0.316 | 0.022 | 0.001 | 0.279 |
| seed treatment | < 0.001 | < 0.001 | < 0.001 | 0.068 | < 0.001 | < 0.001 | < 0.001 | 0.003 | < 0.001 |
| location*plant species | < 0.001 | 0.122 | 0.036 | 0.025 | 0.738 | 0.100 | 0.501 | 0.086 | 0.615 |
| location*seed treatment | 0.532 | 0.004 | 0.023 | 0.456 | < 0.001 | 0.017 | 0.023 | 0.246 | 0.169 |
| plant species*seed treatment | < 0.001 | < 0.001 | 0.039 | < 0.001 | < 0.001 | 0.024 | < 0.001 | < 0.001 | 0.376 |
| location*plant species*seed treatment | 0.656 | 0.160 | < 0.001 | 0.258 | 0.154 | 0.001 | 0.001 | 0.002 | 0.729 |
| 2004 | | | | | | | | | |
| location | < 0.001 | < 0.001 | < 0.001 | 0.093 | < 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 |
| plant species | 0.185 | 0.032 | 0.017 | 0.842 | 0.796 | 0.147 | < 0.001 | 0.002 | < 0.001 |
| seed treatment | 0.000 | < 0.001 | < 0.001 | 0.203 | 0.309 | 0.045 | 0.023 | < 0.001 | 0.002 |
| location*plant species | < 0.001 | < 0.001 | 0.001 | 0.753 | 0.974 | 0.020 | 0.001 | < 0.001 | < 0.001 |
| location*seed treatment | 0.319 | 0.078 | < 0.001 | 0.327 | 0.668 | 0.004 | 0.055 | < 0.001 | < 0.001 |
| plant species*seed treatment | 0.047 | 0.019 | 0.086 | 0.041 | 0.138 | 0.010 | < 0.001 | 0.001 | 0.131 |
| location*plant species*seed treatment | < 0.001 | 0.055 | < 0.001 | < 0.001 | 0.099 | 0.024 | 0.009 | 0.072 | 0.292 |
| 2005 | | | | | | | | | |
| location | 0.576 | < 0.001 | 0.041 | 0.419 | 0.985 | < 0.001 | 0.476 | < 0.001 | 0.000 |
| plant species | < 0.001 | 0.032 | 0.683 | < 0.001 | 0.073 | 0.644 | < 0.001 | 0.039 | < 0.001 |
| seed treatment | < 0.001 | 0.086 | 0.012 | 0.001 | 0.009 | 0.417 | < 0.001 | < 0.001 | 0.012 |
| location*plant species | < 0.001 | 0.465 | 0.219 | 0.005 | 0.785 | 0.009 | 0.444 | 0.026 | 0.764 |
| location*seed treatment | 0.006 | 0.285 | < 0.001 | 0.275 | 0.071 | 0.976 | 0.110 | 0.002 | 0.002 |
| plant species*seed treatment | < 0.001 | < 0.001 | < 0.001 | 0.303 | 0.018 | 0.001 | 0.012 | 0.023 | 0.007 |
| location*plant species*seed treatment | 0.056 | 0.006 | 0.016 | < 0.001 | 0.003 | 0.075 | 0.019 | 0.039 | 0.059 |

Table 12. Mean percent isolation of fungi by location, plant species, and seed treatments, and their interactions, for durum and common wheat in field trials at Sinaluta and Indian Head, in 2003.

| Fungus/Effect | | Mean percent fungal isolation | | | | |
|-------------------------------------|-------------|-------------------------------|----|-----------|-----|----|
| <i>Cochliobolus sativus</i> | | | | | | |
| <u>Location*plant species</u> | | | | | | |
| Location | Durum | | | Wheat | | |
| Indian Head | 5.6 | d | * | 8.6 | c | * |
| Sintaluta | 23.6 | a | * | 14.9 | b | * |
| <u>Plant species*seed treatment</u> | | | | | | |
| Seed treatment | Durum | | | Wheat | | |
| Charter 2.5 | 12.9 | a | * | 9.0 | a | * |
| Dividend XL RTA | 0.8 | b | ns | 0.0 | b | ns |
| Gemini | 8.8 | a | * | 28.8 | a | * |
| JAU | 16.4 | a | * | 11.5 | a | * |
| JAU+Raxil 250 | 20.3 | a | * | 14.9 | a | * |
| Raxil 250 FL | 10.3 | a | * | 11.4 | a | * |
| Raxil 250+Trilex FL | 18.0 | a | * | 10.2 | a | * |
| Raxil T | 16.7 | a | * | 10.6 | a | * |
| VitaFlo 280 (high) | 9.4 | a | * | 10.7 | a | * |
| BASF1 | 8.3 | a | * | 22.2 | a | * |
| BASF2 | 13.6 | a | * | 24.8 | a | * |
| Untreated infected | 15.3 | a | * | 20.7 | a | * |
| Untreated uninfected | 27.4 | a | * | 10.0 | a | * |
| <u>Total <i>Fusarium</i> spp.</u> | | | | | | |
| <u>Location*seed treatment</u> | | | | | | |
| Seed treatment | Indian Head | | | Sintaluta | | |
| Charter 2.5 | 64.3 | a | * | 41.5 | a-e | * |
| Dividend XL RTA | 68.6 | a | * | 59.7 | a | * |
| Gemini | 52.4 | a | * | 26.0 | e | * |
| JAU | 52.5 | a | * | 33.3 | b-e | * |
| JAU+Raxil 250 | 50.3 | a | * | 27.4 | de | * |
| Raxil 250 FL | 49.7 | a | * | 45.2 | a-e | * |
| Raxil 250+Trilex FL | 63.7 | a | * | 49.7 | a-c | * |
| Raxil T | 62.6 | a | * | 31.2 | c-e | * |
| VitaFlo 280 (high) | 59.8 | a | * | 54.6 | ab | * |
| BASF1 | 64.8 | a | * | 49.9 | a-c | * |
| BASF2 | 59.7 | a | * | 34.9 | b-e | * |
| Untreated infected | 60.1 | a | * | 49.4 | a-c | * |
| Untreated uninfected | 51.2 | a | * | 46.3 | a-d | * |
| <u>Plant species*seed treatment</u> | | | | | | |
| Seed treatment | Durum | | | Wheat | | |
| Charter 2.5 | 48.0 | a-c | * | 55.7 | a | * |
| Dividend XL RTA | 64.5 | a | * | 63.6 | a | * |
| Gemini | 58.6 | ab | * | 23.2 | b | * |
| JAU | 41.2 | a-c | * | 42.7 | a | * |
| JAU+Raxil 250 | 32.4 | c | * | 42.6 | a | * |

| | | | | | | |
|----------------------|------|-----|---|------|----|---|
| Raxil 250 FL | 54.8 | a-c | * | 41.0 | ab | * |
| Raxil 250+Trilex FL | 51.1 | a-c | * | 62.0 | a | * |
| Raxil T | 41.4 | a-c | * | 47.4 | a | * |
| Vitaflor 280 (high) | 59.6 | ab | * | 54.8 | a | * |
| BASF1 | 68.4 | a | * | 47.2 | a | * |
| BASF2 | 54.7 | a-c | * | 38.1 | ab | * |
| Untreated infected | 59.9 | ab | * | 49.6 | a | * |
| Untreated uninfected | 38.1 | bc | * | 62.1 | a | * |

F. acuminatum

| Location*plant species*seed treatment | Indian Head | | | Santaluta | | |
|---------------------------------------|-------------|---|---|-----------|----|----|
| | Durum | | | Wheat | | |
| Seed treatment | | | | | | |
| Charter 2.5 | 25.7 | a | * | 11.1 | ab | * |
| Dividend XL RTA | 27.7 | a | * | 6.4 | ab | * |
| Gemini | 25.3 | a | * | 11.3 | ab | * |
| JAU | 9.5 | a | * | 9.3 | ab | * |
| JAU+Raxil 250 | 7.8 | a | * | 10.9 | ab | * |
| Raxil 250 FL | 20.1 | a | * | 3.1 | ab | * |
| Raxil 250+Trilex FL | 14.6 | a | * | 3.6 | ab | * |
| Raxil T | 16.0 | a | * | 5.0 | ab | * |
| Vitaflor 280 (high) | 12.2 | a | * | 1.4 | b | ns |
| BASF1 | 20.6 | a | * | 16.1 | ab | * |
| BASF2 | 34.3 | a | * | 17.9 | ab | * |
| Untreated infected | 16.2 | a | * | 6.3 | ab | * |
| Untreated uninfected | 15.5 | a | * | 24.4 | a | * |

F. avenaceum

Location*plant species

| Location | Durum | | | Wheat | | |
|-------------|-------|----|---|-------|---|---|
| Indian Head | 2.4 | bc | * | 1.3 | c | * |
| Santaluta | 3.3 | ab | * | 4.4 | a | * |

Plant species*seed treatment

| Seed treatment | Durum | | | Wheat | | |
|----------------------|-------|---|----|-------|----|----|
| Charter 2.5 | 5.2 | a | * | 2.0 | ab | * |
| Dividend XL RTA | 2.2 | a | * | 2.5 | ab | * |
| Gemini | 4.2 | a | * | 0.6 | ab | ns |
| JAU | 3.3 | a | * | < 0.1 | b | ns |
| JAU+Raxil 250 | 0.6 | a | ns | 4.4 | ab | * |
| Raxil 250 FL | 5.6 | a | * | 1.5 | ab | * |
| Raxil 250+Trilex FL | 2.9 | a | * | 1.1 | ab | * |
| Raxil T | 6.3 | a | * | 3.5 | ab | * |
| Vitaflor 280 (high) | 0.5 | a | ns | 5.3 | ab | * |
| BASF1 | 3.6 | a | * | 4.2 | ab | * |
| BASF2 | 2.8 | a | * | 8.4 | a | * |
| Untreated infected | 3.1 | a | * | 2.1 | ab | * |
| Untreated uninfected | 1.6 | a | * | 6.1 | ab | * |

F. culmorum

Location*seed treatment**Seed treatment****Indian Head****Sintaluta**

| | | | | | | |
|----------------------|-----|----|----|-------|----|----|
| Charter 2.5 | 0.4 | b | ns | 2.0 | b | * |
| Dividend XL RTA | 3.2 | ab | * | < 0.1 | b | ns |
| Gemini | 2.9 | ab | * | 0.7 | b | ns |
| JAU | 0.5 | b | ns | 0.7 | b | ns |
| JAU+Raxil 250 | 0.5 | b | ns | < 0.1 | b | ns |
| Raxil 250 FL | 0.3 | b | ns | 0.5 | b | ns |
| Raxil 250+Trilex FL | 0.9 | b | ns | 0.5 | b | ns |
| Raxil T | 4.4 | ab | * | 0.6 | b | ns |
| VitaFlo 280 (high) | 1.3 | ab | * | 2.8 | ab | * |
| BASF1 | 4.5 | ab | * | 0.9 | b | ns |
| BASF2 | 4.3 | ab | * | < 0.1 | b | ns |
| Untreated infected | 9.6 | a | * | 2.8 | ab | * |
| Untreated uninfected | 4.1 | ab | * | 12.3 | a | * |

Plant species*seed treatment**Seed treatment****Durum****Wheat**

| | | | | | | |
|----------------------|-------|-----|----|-------|----|----|
| Charter 2.5 | 0.7 | bc | ns | 1.5 | ab | * |
| Dividend XL RTA | 1.0 | bc | * | 1.0 | ab | * |
| Gemini | 1.1 | bc | * | 2.2 | ab | * |
| JAU | < 0.1 | c | ns | 1.6 | ab | * |
| JAU+Raxil 250 | 0.5 | c | ns | < 0.1 | b | ns |
| Raxil 250 FL | 1.0 | bc | * | < 0.1 | b | ns |
| Raxil 250+Trilex FL | 2.0 | bc | * | < 0.1 | b | ns |
| Raxil T | 2.4 | a-c | * | 1.5 | ab | * |
| VitaFlo 280 (high) | 7.9 | ab | * | < 0.1 | b | ns |
| BASF1 | 4.6 | a-c | * | 0.8 | ab | ns |
| BASF2 | 1.5 | bc | * | 1.1 | ab | * |
| Untreated infected | 12.7 | a | * | 1.9 | ab | * |
| Untreated uninfected | 7.2 | ab | * | 7.3 | a | * |

F. equiseti**Location*plant species*seed treatment****Seed treatment****Indian Head****Sintaluta**

| | Durum | | | Wheat | | | Durum | | | Wheat | | |
|----------------------|-------|---|---|-------|---|---|-------|---|----|-------|----|----|
| Charter 2.5 | 8.6 | a | * | 17.8 | a | * | 2.2 | a | * | 6.6 | ab | * |
| Dividend XL RTA | 13.7 | a | * | 15.3 | a | * | 9.6 | a | * | 11.0 | ab | * |
| Gemini | 10.6 | a | * | 15.5 | a | * | 3.1 | a | * | < 0.1 | b | ns |
| JAU | 21.5 | a | * | 14.8 | a | * | 3.1 | a | * | 10.5 | ab | * |
| JAU+Raxil 250 | 11.3 | a | * | 10.2 | a | * | 0.9 | a | ns | 3.8 | ab | * |
| Raxil 250 FL | 17.0 | a | * | 7.9 | a | * | 9.0 | a | * | 4.1 | ab | * |
| Raxil 250+Trilex FL | 20.3 | a | * | 14.0 | a | * | 6.1 | a | * | 3.4 | ab | * |
| Raxil T | 11.6 | a | * | 17.1 | a | * | 2.9 | a | * | < 0.1 | b | ns |
| VitaFlo 280 (high) | 14.6 | a | * | 18.1 | a | * | 7.8 | a | * | 3.7 | ab | * |
| BASF1 | 32.5 | a | * | 23.8 | a | * | 9.7 | a | * | 16.8 | a | * |
| BASF2 | 9.8 | a | * | 19.2 | a | * | 10.4 | a | * | < 0.1 | b | ns |
| Untreated infected | 14.4 | a | * | 15.8 | a | * | 12.3 | a | * | 8.2 | ab | * |
| Untreated uninfected | 16.9 | a | * | 21.2 | a | * | 5.0 | a | * | 10.4 | ab | * |

F. graminearum**Location*plant species*seed treatment****Indian Head****Sintaluta**

| Seed treatment | Durum | | | Wheat | | | Durum | | | Wheat | | |
|----------------------|-------|----|----|-------|---|----|-------|----|----|-------|----|----|
| Charter 2.5 | 17.5 | a | * | 36.9 | a | * | 12.6 | ab | * | 20.7 | a | * |
| Dividend XL RTA | 14.4 | a | * | 34.6 | a | * | 14.9 | ab | * | 27.5 | a | * |
| Gemini | 22.8 | a | * | 1.3 | b | * | 22.7 | a | * | < 0.1 | b | ns |
| JAU | 14.5 | a | * | 26.6 | a | * | 11.6 | ab | * | 21.5 | a | * |
| JAU+Raxil 250 | 23.7 | a | * | 25.6 | a | * | 2.6 | bc | * | 24.8 | a | * |
| Raxil 250 FL | 19.6 | a | * | 21.6 | a | * | 11.1 | ab | * | 26.1 | a | * |
| Raxil 250+Trilex FL | 23.1 | a | * | 41.4 | a | * | 11.9 | ab | * | 30.7 | a | * |
| Raxil T | 26.4 | a | * | 24.6 | a | * | 1.9 | bc | * | 22.1 | a | * |
| Vitaflor 280 (high) | 17.4 | a | * | 33.0 | a | * | 22.6 | a | * | 25.4 | a | * |
| BASF1 | 8.9 | ab | * | < 0.1 | b | ns | 20.0 | a | * | < 0.1 | b | ns |
| BASF2 | 17.4 | a | * | < 0.1 | b | ns | 19.0 | a | * | < 0.1 | b | ns |
| Untreated infected | 13.5 | a | * | 28.7 | a | * | 12.6 | ab | * | 10.4 | ab | * |
| Untreated uninfected | < 0.1 | b | ns | < 0.1 | b | ns | < 0.1 | c | ns | < 0.1 | b | ns |

F. oxysporum

| Location*plant species*seed treatment | Indian Head | | | Santaluta | | |
|---------------------------------------|-------------|---|----|-----------|---|----|
| Seed treatment | Durum | | | Wheat | | |
| Charter 2.5 | 2.6 | a | * | 1.2 | a | ns |
| Dividend XL RTA | 7.5 | a | * | 3.8 | a | * |
| Gemini | 2.1 | a | * | 7.0 | a | * |
| JAU | 5.5 | a | * | 1.0 | a | ns |
| JAU+Raxil 250 | 2.9 | a | * | 1.2 | a | ns |
| Raxil 250 FL | 3.5 | a | * | 1.4 | a | ns |
| Raxil 250+Trilex FL | 0.9 | a | ns | 5.1 | a | * |
| Raxil T | 1.0 | a | ns | 4.4 | a | * |
| Vitaflor 280 (high) | 7.2 | a | * | 3.1 | a | * |
| BASF1 | 2.0 | a | * | 8.9 | a | * |
| BASF2 | 6.1 | a | * | 1.5 | a | * |
| Untreated infected | 5.1 | a | * | 2.1 | a | * |
| Untreated uninfected | 6.2 | a | * | 1.2 | a | ns |

Microdochium bolleyi

| Seed treatment | |
|----------------------|------------|
| Charter 2.5 | 17.6 a * |
| Dividend XL RTA | 16.1 a * |
| Gemini | 13.5 ab * |
| JAU | 14.8 a * |
| JAU+Raxil 250 | 10.6 a-d * |
| Raxil 250 FL | 16.2 a * |
| Raxil 250+Trilex FL | 5.2 d ns |
| Raxil T | 10.6 a-d * |
| Vitaflor 280 (high) | 8.2 a-d * |
| BASF1 | 5.6 cd * |
| BASF2 | 12.8 a-c * |
| Untreated infected | 13.0 a-c * |
| Untreated uninfected | 6.0 b-d * |

Means in a column for an effect or an interaction followed by the same letter are not significantly different ($P < 0.05$).

*, value is significantly different from 0; ns, value is not significantly different from 0.

Table 13. Mean percent isolation of fungi by location, plant species, and seed treatments, and their interactions, for barley, durum and common wheat in field trials at Canora, Sinaluta and Indian Head, in 2004.

Fungus/Effect

Mean percent fungal isolation

Cochliobolus sativus

Location*plant species*seed treatment

| Seed treatment | Canora | | | | | | Indian Head | | | | | | Sinaluta | | | | | |
|----------------------|--------|------|-------|------|-------|------|-------------|-----|-------|------|-------|-----|----------|------|-------|------|-------|------|
| | Barley | | Durum | | Wheat | | Barley | | Durum | | Wheat | | Barley | | Durum | | Wheat | |
| Charter 2.5 | < 0.1 | a ns | 0.8 | a ns | < 0.1 | a ns | 9.8 | a * | 10.6 | a * | 4.9 | a * | 7.9 | a * | 2.2 | a * | < 0.1 | a ns |
| Dividend XL RTA | 1.9 | a * | 4.3 | a * | < 0.1 | a ns | 27.8 | a * | 9.0 | a * | 11.7 | a * | < 0.1 | a ns | < 0.1 | a ns | 2.4 | a * |
| Gemini | < 0.1 | a ns | 0.1 | a ns | < 0.1 | a ns | 14.9 | a * | 11.6 | a * | 4.8 | a * | 10.7 | a * | 1.9 | a * | 13.5 | a * |
| Maxim 480 FS | < 0.1 | a ns | < 0.1 | a ns | < 0.1 | a ns | 9.4 | a * | 20.9 | a * | 7.0 | a * | 6.3 | a * | 4.5 | a * | 1.8 | a * |
| Raxil 250 FL | < 0.1 | a ns | < 0.1 | a ns | 0.2 | a ns | 10.6 | a * | 6.9 | a * | 14.1 | a * | < 0.1 | a ns | 2.4 | a * | 11.9 | a * |
| Raxil MD | 1.4 | a ns | < 0.1 | a ns | < 0.1 | a ns | 23.0 | a * | 15.4 | a * | 5.6 | a * | < 0.1 | a ns | 1.3 | a ns | < 0.1 | a ns |
| Raxil T | 2.0 | a * | < 0.1 | a ns | < 0.1 | a ns | 21.4 | a * | 14.2 | a * | 7.1 | a * | < 0.1 | a ns | < 0.1 | a ns | 27.0 | a * |
| VitaFlo 280 (low) | < 0.1 | a ns | < 0.1 | a ns | 0.9 | a ns | 24.7 | a * | 9.5 | a * | 3.1 | a * | 3.4 | a * | 4.1 | a * | 1.7 | a ns |
| VitaFlo 280 (high) | < 0.1 | a ns | 1.0 | a ns | 0.2 | a ns | 19.8 | a * | 21.7 | a * | 6.8 | a * | 4.9 | a * | 1.5 | a ns | 6.4 | a * |
| BASF3 | 0.8 | a ns | < 0.1 | a ns | 1.7 | a * | 39.9 | a * | 1.5 | a ns | 5.5 | a * | 6.2 | a * | 17.0 | a * | 1.8 | a * |
| BASF4 | < 0.1 | a ns | < 0.1 | a ns | < 0.1 | a ns | 20.6 | a * | 10.4 | a * | 5.7 | a * | 6.1 | a * | 7.9 | a * | < 0.1 | a ns |
| Bayer1 | < 0.1 | a ns | 1.8 | a * | < 0.1 | a ns | 23.9 | a * | 21.9 | a * | 15.4 | a * | 8.8 | a * | < 0.1 | a ns | < 0.1 | a ns |
| Untreated infected | < 0.1 | a ns | 1.2 | a ns | 0.9 | a ns | 14.0 | a * | 15.1 | a * | 11.5 | a * | < 0.1 | a ns | 20.0 | a * | 3.4 | a * |
| Untreated uninfected | < 0.1 | a ns | < 0.1 | a ns | < 0.1 | a ns | 15.2 | a * | 6.9 | a * | 7.8 | a * | 8.3 | a * | 2.0 | a * | 10.7 | a * |

Total *Fusarium* spp.

Location*plant species

| Plant species | Canora | | Indian Head | | Sinaluta | |
|---------------|--------|------|-------------|-------|----------|-------|
| barley | 6.9 | d * | 19.5 | ab * | 22.3 | a * |
| durum wheat | 10.0 | cd * | 12.1 | b-d * | 13.9 | a-c * |
| common wheat | 9.5 | cd * | 17.8 | ab * | 8.0 | cd * |

Plant species*seed treatment

| Seed treatment | Barley | | Durum | | Wheat | |
|-------------------|--------|-----|-------|------|-------|-------|
| Charter 2.5 | 12.2 | a * | 15.5 | ab * | 15.6 | a-c * |
| Dividend XL RTA | 29.0 | a * | 26.8 | a * | 11.8 | a-c * |
| Gemini | 14.3 | a * | 4.3 | b ns | 9.1 | a-c * |
| Maxim 480 FS | 14.9 | a * | 13.9 | ab * | 7.2 | a-c * |
| Raxil 250 FL | 13.1 | a * | 11.0 | ab * | 14.3 | a-c * |
| Raxil MD | 13.7 | a * | 9.1 | ab * | 11.1 | a-c * |
| Raxil T | 13.8 | a * | 20.6 | ab * | 19.2 | ab * |
| VitaFlo 280 (low) | 13.1 | a * | 8.2 | a * | 9.4 | a-c * |

| | | | | | | | | | |
|----------------------|------|---|---|------|----|---|------|-----|----|
| VitaFlo 280 (high) | 15.0 | a | * | 8.6 | ab | * | 18.0 | a-c | * |
| BASF3 | 12.5 | a | * | 13.7 | ab | * | 23.8 | a | * |
| BASF4 | 18.3 | a | * | 16.8 | ab | * | 16.1 | a-c | * |
| Bayer1 | 9.0 | a | * | 9.1 | ab | * | 3.7 | bc | * |
| Untreated infected | 18.4 | a | * | 9.2 | ab | * | 14.3 | a-c | * |
| Untreated uninfected | 13.1 | a | * | 14.0 | ab | * | 2.6 | c | ns |

F. acuminatum

Location*plant species*seed treatment

| Seed treatment | Canora | | | | | | | | |
|----------------------|--------|---|----|-------|---|----|-------|---|----|
| | Barley | | | Durum | | | Wheat | | |
| Charter 2.5 | 1.1 | a | ns | 6.7 | a | * | 2.6 | a | * |
| Dividend XL RTA | 0.3 | a | ns | 9.8 | a | * | 2.6 | a | * |
| Gemini | <0.1 | a | ns | 1.3 | a | ns | <0.1 | a | ns |
| Maxim 480 FS | <0.1 | a | ns | 2.3 | a | * | 3.4 | a | * |
| Raxil 250 FL | 0.8 | a | ns | 0.9 | a | ns | 0.3 | a | ns |
| Raxil MD | 0.5 | a | ns | 2.3 | a | * | <0.1 | a | ns |
| Raxil T | <0.1 | a | ns | 2.0 | a | * | 4.4 | a | * |
| VitaFlo 280 (low) | <0.1 | a | ns | 1.0 | a | ns | <0.1 | a | ns |
| VitaFlo 280 (high) | <0.1 | a | ns | 2.2 | a | * | 0.3 | a | ns |
| BASF3 | 0.9 | a | ns | 1.8 | a | * | 1.4 | a | ns |
| BASF4 | 1.8 | a | * | <0.1 | a | ns | <0.1 | a | ns |
| Bayer1 | <0.1 | a | ns | <0.1 | a | ns | 1.5 | a | ns |
| Untreated infected | 1.6 | a | ns | 1.2 | a | ns | 0.7 | a | ns |
| Untreated uninfected | <0.1 | a | ns | <0.1 | a | ns | 1.3 | a | ns |

Indian Head

| Seed treatment | Barley | | | Durum | | | Wheat | | |
|----------------------|--------|---|----|-------|---|----|-------|---|----|
| | | | | | | | | | |
| Charter 2.5 | 7.8 | a | * | 11.2 | a | * | 4.9 | a | * |
| Dividend XL RTA | 13.9 | a | * | 16.3 | a | * | 1.6 | a | ns |
| Gemini | 14.0 | a | * | 5.1 | a | * | <0.1 | a | ns |
| Maxim 480 FS | 13.3 | a | * | 7.7 | a | * | 1.9 | a | ns |
| Raxil 250 FL | 2.1 | a | * | 7.4 | a | * | 3.1 | a | * |
| Raxil MD | 2.7 | a | * | <0.1 | a | ns | 7.2 | a | * |
| Raxil T | 7.5 | a | * | 8.2 | a | * | 4.7 | a | * |
| VitaFlo 280 (low) | 7.1 | a | * | 2.7 | a | * | 1.6 | a | ns |
| VitaFlo 280 (high) | 8.4 | a | * | 0.8 | a | ns | 1.9 | a | * |
| BASF3 | 12.5 | a | * | 11.7 | a | * | 7.6 | a | * |
| BASF4 | 5.4 | a | * | 8.2 | a | * | 7.3 | a | * |
| Bayer1 | <0.1 | a | ns | 1.1 | a | ns | 7.2 | a | * |
| Untreated infected | 7.0 | a | * | 10.1 | a | * | 3.6 | a | * |
| Untreated uninfected | 20.9 | a | * | 6.7 | a | * | 4.0 | a | * |

Sintaluta

| Seed treatment | Barley | | | Durum | | | Wheat | | |
|----------------------|--------|---|----|-------|---|----|-------|---|----|
| | | | | | | | | | |
| Charter 2.5 | 8.1 | a | * | 1.5 | a | ns | <0.1 | a | ns |
| Dividend XL RTA | 14.2 | a | * | <0.1 | a | ns | <0.1 | a | ns |
| Gemini | 5.4 | a | * | <0.1 | a | ns | 5.9 | a | * |
| Maxim 480 FS | 3.6 | a | * | <0.1 | a | ns | <0.1 | a | ns |
| Raxil 250 FL | 6.4 | a | * | 12.3 | a | * | 4.2 | a | * |
| Raxil MD | 1.3 | a | ns | 26.4 | a | * | <0.1 | a | ns |
| Raxil T | 3.7 | a | * | <0.1 | a | ns | 1.8 | a | * |
| VitaFlo 280 (low) | <0.1 | a | ns | 1.9 | a | * | 1.9 | a | * |
| VitaFlo 280 (high) | 6.8 | a | * | 5.3 | a | * | 7.6 | a | * |
| BASF3 | 2.7 | a | * | 4.9 | a | * | 20.6 | a | * |
| BASF4 | 5.6 | a | * | <0.1 | a | ns | <0.1 | a | ns |
| Bayer1 | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |
| Untreated infected | 13.0 | a | * | 11.6 | a | * | 6.2 | a | * |
| Untreated uninfected | 11.1 | a | * | 4.1 | a | * | <0.1 | a | ns |

F. avenaceum

Location*plant species*seed treatment

| Seed treatment | Canora | | | | | | | | |
|--------------------|--------|---|----|-------|---|----|-------|---|----|
| | Barley | | | Durum | | | Wheat | | |
| Charter 2.5 | <0.1 | a | ns | <0.1 | a | ns | 1.9 | a | * |
| Dividend XL RTA | 2.1 | a | * | <0.1 | a | ns | <0.1 | a | ns |
| Gemini | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |
| Maxim 480 FS | <0.1 | a | ns | 1.1 | a | ns | <0.1 | a | ns |
| Raxil 250 FL | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |
| Raxil MD | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |
| Raxil T | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |
| VitaFlo 280 (low) | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |
| VitaFlo 280 (high) | <0.1 | a | ns | 0.8 | a | ns | 3.4 | a | * |
| BASF3 | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |
| BASF4 | 0.7 | a | ns | <0.1 | a | ns | 1.0 | a | ns |
| Bayer1 | 2.4 | a | * | <0.1 | a | ns | <0.1 | a | ns |

Indian Head

| Seed treatment | Barley | | | Durum | | | Wheat | | |
|--------------------|--------|---|----|-------|---|----|-------|---|----|
| | | | | | | | | | |
| Charter 2.5 | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |
| Dividend XL RTA | 4.2 | a | * | <0.1 | a | ns | <0.1 | a | ns |
| Gemini | <0.1 | a | ns | 1.1 | a | ns | <0.1 | a | ns |
| Maxim 480 FS | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |
| Raxil 250 FL | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |
| Raxil MD | <0.1 | a | ns | 2.0 | a | * | <0.1 | a | ns |
| Raxil T | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |
| VitaFlo 280 (low) | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |
| VitaFlo 280 (high) | <0.1 | a | ns | 0.9 | a | ns | 1.0 | a | ns |
| BASF3 | <0.1 | a | ns | <0.1 | a | ns | 2.8 | a | * |
| BASF4 | <0.1 | a | ns | 0.6 | a | ns | <0.1 | a | ns |
| Bayer1 | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |

Sintaluta

| Seed treatment | Barley | | | Durum | | | Wheat | | |
|--------------------|--------|---|----|-------|---|----|-------|---|----|
| | | | | | | | | | |
| Charter 2.5 | <0.1 | a | ns | 10.8 | a | * | <0.1 | a | ns |
| Dividend XL RTA | 3.5 | a | * | <0.1 | a | ns | 4.8 | a | * |
| Gemini | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |
| Maxim 480 FS | <0.1 | a | ns | 7.2 | a | * | <0.1 | a | ns |
| Raxil 250 FL | <0.1 | a | ns | <0.1 | a | ns | 3.6 | a | * |
| Raxil MD | 4.3 | a | * | <0.1 | a | ns | 2.8 | a | * |
| Raxil T | <0.1 | a | ns | <0.1 | a | ns | 1.6 | a | * |
| VitaFlo 280 (low) | <0.1 | a | ns | 2.3 | a | * | 1.7 | a | * |
| VitaFlo 280 (high) | 12.2 | a | * | <0.1 | a | ns | <0.1 | a | ns |
| BASF3 | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |
| BASF4 | <0.1 | a | ns | 2.3 | a | * | <0.1 | a | ns |
| Bayer1 | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |

| | | | | | | | | | | | | | | | | | | |
|----------------------|-----|------|------|------|------|------|-----|-----|------|------|-----|------|------|------|------|------|------|------|
| Untreated infected | 1.8 | a * | <0.1 | a ns | <0.1 | a ns | 1.3 | a * | <0.1 | a ns | 0.9 | a ns | <0.1 | a ns | 1.3 | a * | <0.1 | a ns |
| Untreated uninfected | 0.8 | a ns | <0.1 | a ns | <0.1 | a ns | 1.6 | a * | <0.1 | a ns | 5.4 | a * | <0.1 | a ns | <0.1 | a ns | <0.1 | a ns |

F. culmorum

Location

| | | |
|-------------|-----|------|
| Canora | 0.1 | b ns |
| Sintaluta | 0.1 | b ns |
| Indian Head | 1.4 | a * |

F. equiseti

Location*plant species*seed treatment

| Seed treatment | Canora | | | | | | Indian Head | | | | | | Sintaluta | | | | | |
|----------------------|--------|------|-------|-----|-------|------|-------------|------|-------|------|-------|------|-----------|------|-------|------|-------|------|
| | Barley | | Durum | | Wheat | | Barley | | Durum | | Wheat | | Barley | | Durum | | Wheat | |
| Charter 2.5 | 2.1 | a * | 3.0 | a * | 8.4 | a * | 4.8 | a * | 2.2 | a * | 2.5 | a * | <0.1 | a ns | <0.1 | a ns | <0.1 | a ns |
| Dividend XL RTA | 2.5 | a * | 7.7 | a * | 10.5 | a * | <0.1 | a ns | 2.1 | a * | <0.1 | a ns | 4.1 | a * | <0.1 | a ns | <0.1 | a ns |
| Gemini | 0.3 | a ns | 6.7 | a * | 4.0 | a * | 1.0 | a ns | <0.1 | a ns | <0.1 | a ns | <0.1 | a ns | <0.1 | a ns | <0.1 | a ns |
| Maxim 480 FS | 7.2 | a * | 8.2 | a * | 5.4 | a * | <0.1 | a ns | 2.2 | a * | <0.1 | a ns | <0.1 | a ns | <0.1 | a ns | <0.1 | a ns |
| Raxil 250 FL | 8.1 | a * | 5.8 | a * | 1.7 | a * | <0.1 | a ns | 3.0 | a * | <0.1 | a ns | <0.1 | a ns | <0.1 | a ns | <0.1 | a ns |
| Raxil MD | 9.7 | a * | 4.2 | a * | 3.7 | a * | 1.1 | a ns | <0.1 | a ns | <0.1 | a ns | 3.9 | a * | <0.1 | a ns | 5.9 | a * |
| Raxil T | 5.7 | a * | 8.8 | a * | 4.6 | a * | 4.2 | a * | 7.1 | a * | 2.2 | a * | <0.1 | a ns | <0.1 | a ns | <0.1 | a ns |
| VitaFlo 280 (low) | 3.3 | a * | 8.7 | a * | 8.7 | a * | 1.7 | a * | <0.1 | a ns | 1.8 | a * | <0.1 | a ns | <0.1 | a ns | <0.1 | a ns |
| VitaFlo 280 (high) | 4.2 | a * | 2.6 | a * | 9.0 | a * | <0.1 | a ns | 1.8 | a * | 2.3 | a * | <0.1 | a ns | <0.1 | a ns | <0.1 | a ns |
| BASF3 | 4.1 | a * | 9.1 | a * | 3.0 | a * | 6.0 | a * | 2.7 | a * | <0.1 | a ns | 0.8 | a ns | 4.1 | a * | <0.1 | a ns |
| BASF4 | 5.7 | a * | 4.2 | a * | 18.0 | a * | 2.5 | a * | 10.5 | a * | <0.1 | a ns | <0.1 | a ns | 1.8 | a * | <0.1 | a ns |
| Bayer I | 1.4 | a * | 4.9 | a * | 1.6 | a ns | 0.8 | a ns | <0.1 | a ns | <0.1 | a ns | 0.8 | a ns | <0.1 | a ns | <0.1 | a ns |
| Untreated infected | 3.5 | a * | 2.4 | a * | 3.5 | a * | 2.5 | a * | <0.1 | a ns | 1.3 | a ns | 1.3 | a ns | <0.1 | a ns | 6.5 | a * |
| Untreated uninfected | 2.0 | a * | 9.3 | a * | 1.0 | a ns | 1.5 | a * | 13.3 | a * | <0.1 | a ns | 2.7 | a * | <0.1 | a ns | <0.1 | a ns |

F. graminearum

Location*plant species*seed treatment

| Seed treatment | Canora | | | | | | Indian Head | | | | | | Sintaluta | | | | | |
|--------------------|--------|------|-------|------|-------|------|-------------|------|-------|------|-------|-----|-----------|------|-------|------|-------|------|
| | Barley | | Durum | | Wheat | | Barley | | Durum | | Wheat | | Barley | | Durum | | Wheat | |
| Charter 2.5 | 2.8 | a * | <0.1 | a ns | 1.6 | a * | 3.0 | a * | <0.1 | a ns | 10.3 | a * | 4.0 | a ns | <0.1 | a ns | 4.1 | a * |
| Dividend XL RTA | 2.3 | a * | <0.1 | a ns | <0.1 | a ns | 11.2 | a * | <0.1 | a ns | 3.5 | a * | <0.1 | a * | <0.1 | a ns | 4.8 | a * |
| Gemini | 6.3 | a * | <0.1 | a ns | <0.1 | a ns | 2.8 | a * | 1.2 | a ns | 18.3 | a * | 2.1 | a * | <0.1 | a ns | <0.1 | a ns |
| Maxim 480 FS | <0.1 | a ns | <0.1 | a ns | 2.5 | a * | <0.1 | a ns | <0.1 | a ns | 5.3 | a * | <0.1 | a ns | <0.1 | a ns | <0.1 | a ns |
| Raxil 250 FL | 1.2 | a ns | 2.1 | a * | 1.9 | a * | 2.9 | a * | 3.1 | a * | 18.8 | a * | <0.1 | a * | <0.1 | a ns | <0.1 | a ns |
| Raxil MD | 1.8 | a * | <0.1 | a ns | 1.8 | a * | 1.4 | a * | <0.1 | a ns | 17.0 | a * | <0.1 | a * | <0.1 | a ns | <0.1 | a ns |
| Raxil T | 1.3 | a * | <0.1 | a ns | 3.7 | a * | 4.1 | a * | <0.1 | a ns | 6.1 | a * | <0.1 | a ns | <0.1 | a ns | <0.1 | a ns |
| VitaFlo 280 (low) | 1.9 | a * | <0.1 | a ns | 2.7 | a * | 2.3 | a * | <0.1 | a ns | 8.2 | a * | 4.9 | a * | <0.1 | a ns | <0.1 | a ns |
| VitaFlo 280 (high) | 1.5 | a * | <0.1 | a ns | <0.1 | a ns | 3.8 | a * | 2.1 | a * | 6.0 | a * | <0.1 | a ns | <0.1 | a ns | <0.1 | a ns |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|----------------------|------|---|----|------|---|----|------|---|----|------|---|----|------|---|----|------|---|----|------|---|----|------|---|----|------|---|----|
| BASF3 | 0.8 | a | ns | 0.6 | a | ns | 4.4 | a | * | 5.4 | a | * | <0.1 | a | ns | 10.4 | a | * | <0.1 | a | ns | <0.1 | a | ns | 3.2 | a | * |
| BASF4 | 0.4 | a | ns | <0.1 | a | ns | 2.5 | a | * | 9.5 | a | * | 1.7 | a | * | 4.7 | a | * | 1.7 | a | ns | <0.1 | a | ns | <0.1 | a | ns |
| Bayer1 | 0.5 | a | ns | <0.1 | a | ns | <0.1 | a | ns | 6.9 | a | * | 1.2 | a | ns | <0.1 | a | ns | 5.6 | a | ns | <0.1 | a | ns | 2.8 | a | * |
| Untreated infected | 3.3 | a | * | <0.1 | a | ns | 2.2 | a | * | 7.0 | a | * | <0.1 | a | ns | 6.7 | a | * | 2.0 | a | | <0.1 | a | ns | <0.1 | a | ns |
| Untreated uninfected | <0.1 | a | ns | 1.6 | a | * | <0.1 | a | ns | <0.1 | a | ns | 1.0 | a | ns | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns | <0.1 | a | ns |

F. oxysporum

Location*plant species

| Plant species | Canora | | | Indian Head | | | Sintaluta | | |
|---------------|--------|---|----|-------------|----|---|-----------|---|---|
| barley | 0.1 | d | ns | 0.7 | cd | * | 9.0 | a | * |
| durum wheat | 0.2 | d | ns | 0.6 | cd | * | 1.9 | c | * |
| common wheat | 0.4 | d | * | 0.6 | cd | * | 5.1 | b | * |

Location*seed treatment

| Seed treatment | Canora | | | Indian Head | | | Sintaluta | | |
|----------------------|--------|---|----|-------------|---|----|-----------|-----|---|
| Charter 2.5 | 0.0 | a | ns | 0.9 | a | * | 1.7 | bc | * |
| Dividend XL RTA | 0.2 | a | ns | 1.9 | a | * | 14.8 | a | * |
| Gemini | 0.2 | a | ns | 0.0 | a | ns | 1.2 | c | * |
| Maxim 480 FS | 0.3 | a | ns | 0.8 | a | ns | 8.0 | a-c | * |
| Raxil 250 FL | 0.9 | a | * | 0.0 | a | ns | 1.3 | bc | * |
| Raxil MD | 0.4 | a | ns | 0.3 | a | ns | 6.3 | a-c | * |
| Raxil T | 0.3 | a | ns | 1.0 | a | * | 11.3 | a | * |
| VitaFlo 280 (low) | 0.3 | a | ns | 0.5 | a | ns | 3.7 | a-c | * |
| VitaFlo 280 (high) | 0.0 | a | ns | 1.5 | a | * | 9.2 | ab | * |
| BASF3 | 0.0 | a | ns | 2.1 | a | * | 6.5 | a-c | * |
| BASF4 | 0.3 | a | ns | 0.2 | a | ns | 13.5 | a | * |
| Bayer1 | 0.2 | a | ns | 0.0 | a | ns | 2.9 | a-c | * |
| Untreated infected | 0.0 | a | ns | 1.8 | a | * | 2.0 | bc | * |
| Untreated uninfected | 0.5 | a | ns | 0.0 | a | ns | 2.0 | bc | * |

Plant species*seed treatment

| Seed treatment | Barley | | | Durum | | | Wheat | | |
|--------------------|--------|---|----|-------|----|----|-------|---|----|
| Charter 2.5 | 0.8 | a | ns | 0.0 | b | ns | 1.9 | a | * |
| Dividend XL RTA | 3.6 | a | * | 6.4 | a | * | 0.6 | a | ns |
| Gemini | 1.7 | a | * | 0.0 | b | ns | 0.0 | a | ns |
| Maxim 480 FS | 3.2 | a | * | 1.7 | ab | * | 0.9 | a | * |
| Raxil 250 FL | 2.0 | a | * | 0.0 | b | ns | 0.4 | a | ns |
| Raxil MD | 1.5 | a | * | 1.2 | ab | * | 1.3 | a | * |
| Raxil T | 1.9 | a | * | 4.2 | ab | * | 1.1 | a | * |
| VitaFlo 280 (low) | 2.6 | a | * | 1.7 | ab | * | 0.0 | a | ns |
| VitaFlo 280 (high) | 2.4 | a | * | 1.0 | ab | * | 2.6 | a | * |
| BASF3 | 2.0 | a | * | 1.7 | ab | * | 1.8 | a | * |
| BASF4 | 1.7 | a | * | 2.9 | ab | * | 1.1 | a | * |

| | | | | | | | | | |
|----------------------|-----|---|----|-----|----|----|-----|---|----|
| Bayerl | 0.3 | a | ns | 2.8 | ab | * | 0.0 | a | ns |
| Untreated infected | 0.8 | a | * | 0.9 | ab | * | 1.4 | a | * |
| Untreated uninfected | 1.2 | a | * | 0.8 | ab | ns | 0.1 | a | ns |

Microdochium bolleyi

Location*plant species

| Plant species | Canora | | | Indian Head | | | Sintaluta | | |
|---------------|--------|---|---|-------------|----|---|-----------|---|---|
| barley | 4.7 | b | * | 14.7 | a | * | 8.4 | b | * |
| durum wheat | 12.0 | a | * | 9.2 | b | * | 24.0 | a | * |
| common wheat | 15.5 | a | * | 13.2 | ab | * | 28.0 | a | * |

Location*seed treatment

| Seed treatment | Canora | | | Indian Head | | | Sintaluta | | |
|----------------------|--------|----|---|-------------|---|---|-----------|----|---|
| Charter 2.5 | 13.7 | ab | * | 12.9 | a | * | 26.2 | ab | * |
| Dividend XL RTA | 27.5 | a | * | 23.2 | a | * | 10.7 | b | * |
| Gemini | 6.4 | ab | * | 17.7 | a | * | 13.6 | ab | * |
| Maxim 480 FS | 9.9 | ab | * | 14.8 | a | * | 19.9 | ab | * |
| Raxil 250 FL | 15.5 | ab | * | 12.6 | a | * | 18.3 | ab | * |
| Raxil MD | 13.1 | ab | * | 16.5 | a | * | 25.2 | ab | * |
| Raxil T | 7.4 | ab | * | 10.2 | a | * | 15.4 | ab | * |
| VitaFlo 280 (low) | 15.4 | ab | * | 10.7 | a | * | 15.6 | ab | * |
| VitaFlo 280 (high) | 7.8 | ab | * | 9.7 | a | * | 11.5 | b | * |
| BASF3 | 5.0 | b | * | 6.9 | a | * | 12.4 | ab | * |
| BASF4 | 8.6 | ab | * | 10.0 | a | * | 26.1 | ab | * |
| Bayerl | 8.0 | ab | * | 10.3 | a | * | 30.2 | ab | * |
| Untreated infected | 14.5 | ab | * | 12.9 | a | * | 11.1 | b | * |
| Untreated uninfected | 5.5 | b | * | 12.3 | a | * | 49.8 | a | * |

Means in a column for an effect or an interaction followed by the same letter are not significantly different ($P < 0.05$).

*, value is significantly different from 0; ns, value is not significantly different from 0.

Table 14. Mean percent isolation of fungi by location, plant species, and seed treatments, and their interactions, for barley and common wheat in field trials at Indian Head and Redvers, in 2005.

| Fungus/Effect | | Mean percent fungal isolation | | | |
|--|--|-------------------------------|-------|---------|-------|
| <i>Cochliobolus sativus</i> | | | | | |
| <u>Location*plant species</u> | | | | | |
| Plant species | | Indian Head | | Redvers | |
| barley | | 55.9 | a * | 30.9 | b * |
| common wheat | | 6.4 | d * | 13.5 | c * |
| <u>Location*seed treatment</u> | | | | | |
| Seed treatment | | Indian Head | | Redvers | |
| Charter 2.5 | | 32.8 | ab * | 26.3 | a * |
| Dividend XL RTA | | 4.6 | d * | 2.7 | b * |
| Gemini | | 21.5 | a-d * | 17.8 | a * |
| Maxim 480 FS | | 32.2 | ab * | 23.8 | a * |
| Raxil 250 FL | | 17.6 | a-d * | 28.9 | a * |
| Raxil MD | | 35.6 | ab * | 24.3 | a * |
| Raxil T | | 7.1 | cd * | 15.5 | a * |
| VitaFlo 280 (low) | | 17.9 | a-d * | 24.7 | a * |
| VitaFlo 280 (high) | | 23.2 | a-c * | 30.2 | a * |
| BASF3 | | 14.3 | b-d * | 30.8 | a * |
| BASF4 | | 16.7 | a-d * | 15.8 | a * |
| Bayer1 | | 14.5 | a-d * | 25.4 | a * |
| Untreated infected | | 34.4 | ab * | 33.1 | a * |
| Untreated uninfected | | 43.7 | a * | 19.5 | a * |
| <u>Plant species*seed treatment</u> | | | | | |
| Seed treatment | | Barley | | Wheat | |
| Charter 2.5 | | 45.8 | a * | 18.7 | ab * |
| Dividend XL RTA | | 13.1 | b * | 0.5 | d ns |
| Gemini | | 54.5 | a * | 6.6 | bc * |
| Maxim 480 FS | | 40.5 | a * | 18.8 | ab * |
| Raxil 250 FL | | 49.0 | a * | 10.1 | b * |
| Raxil MD | | 59.2 | a * | 14.4 | ab * |
| Raxil T | | 52.5 | a * | 1.5 | cd * |
| VitaFlo 280 (low) | | 46.4 | a * | 9.3 | bc * |
| VitaFlo 280 (high) | | 58.8 | a * | 11.7 | ab * |
| BASF3 | | 37.4 | ab * | 11.7 | ab * |
| BASF4 | | 33.3 | ab * | 7.7 | bc * |
| Bayer1 | | 41.2 | a * | 8.7 | bc * |
| Untreated infected | | 61.4 | a * | 18.3 | ab * |
| Untreated uninfected | | 25.9 | ab * | 33.0 | a * |
| <u>Total <i>Fusarium</i> spp.</u> | | | | | |
| <u>Location*plant species*seed treatment</u> | | Indian Head | | Redvers | |
| Seed treatment | | Barley | Wheat | Barley | Wheat |
| Charter 2.5 | | 26.7 | a * | 40.1 | a * |
| Dividend XL RTA | | 44.7 | a * | 61.5 | a * |
| Gemini | | 6.4 | a * | 31.9 | a * |
| Maxim 480 FS | | 17.5 | a * | 35.1 | a * |
| Raxil 250 FL | | 18.8 | a * | 43.8 | ab * |
| Raxil MD | | 9.4 | a * | 24.8 | a * |

| | | | | | | | | | | | | |
|----------------------|------|---|---|------|----|---|------|---|---|------|---|---|
| Raxil T | 18.7 | a | * | 21.9 | ab | * | 26.3 | a | * | 36.8 | a | * |
| Vitaflo 280 (low) | 39.6 | a | * | 15.0 | ab | * | 23.5 | a | * | 35.4 | a | * |
| Vitaflo 280 (high) | 11.5 | a | * | 23.8 | ab | * | 20.8 | a | * | 36.0 | a | * |
| BASF3 | 34.1 | a | * | 25.5 | ab | * | 30.3 | a | * | 25.3 | a | * |
| BASF4 | 8.5 | a | * | 29.3 | ab | * | 33.0 | a | * | 37.7 | a | * |
| Bayer1 | 26.3 | a | * | 11.3 | ab | * | 26.6 | a | * | 33.7 | a | * |
| Untreated infected | 9.9 | a | * | 50.9 | ab | * | 26.6 | a | * | 30.0 | a | * |
| Untreated uninfected | 35.3 | a | * | 8.1 | b | * | 29.8 | a | * | 27.7 | a | * |

F. acuminatum

| Location*plant species*seed treatment | Indian Head | | | | | | Redvers | | | | | |
|---------------------------------------|-------------|---|----|-------|---|----|---------|---|----|-------|---|----|
| | Barley | | | Wheat | | | Barley | | | Wheat | | |
| Seed treatment | | | | | | | | | | | | |
| Charter 2.5 | 4.3 | a | * | 4.7 | a | * | 4.1 | a | * | 6.0 | a | * |
| Dividend XL RTA | 4.5 | a | * | < 0.1 | a | ns | 6.9 | a | * | < 0.1 | a | ns |
| Gemini | < 0.1 | a | ns | < 0.1 | a | ns | 4.5 | a | * | 2.2 | a | * |
| Maxim 480 FS | < 0.1 | a | ns | < 0.1 | a | ns | 6.6 | a | * | 1.8 | a | * |
| Raxil 250 FL | 3.3 | a | * | < 0.1 | a | ns | 0.9 | a | ns | 3.3 | a | * |
| Raxil MD | < 0.1 | a | ns | < 0.1 | a | ns | 2.7 | a | * | < 0.1 | a | ns |
| Raxil T | < 0.1 | a | ns | 16.0 | a | * | 1.1 | a | ns | < 0.1 | a | ns |
| Vitaflo 280 (low) | 2.3 | a | * | < 0.1 | a | ns | 3.3 | a | * | < 0.1 | a | ns |
| Vitaflo 280 (high) | < 0.1 | a | ns | 7.7 | a | * | < 0.1 | a | ns | < 0.1 | a | ns |
| BASF3 | < 0.1 | a | ns | < 0.1 | a | ns | 5.3 | a | * | 1.8 | a | * |
| BASF4 | < 0.1 | a | ns | 4.9 | a | * | < 0.1 | a | ns | 2.3 | a | * |
| Bayer1 | 1.5 | a | * | < 0.1 | a | ns | < 0.1 | a | ns | 2.9 | a | * |
| Untreated infected | 1.7 | a | * | 2.3 | a | * | 1.4 | a | ns | 0.7 | a | ns |
| Untreated uninfected | < 0.1 | a | ns | < 0.1 | a | ns | 3.2 | a | * | 6.2 | a | * |

F. avenaceum

| Location*plant species*seed treatment | Indian Head | | | | | | Redvers | | | | | |
|---------------------------------------|-------------|----|----|-------|---|----|---------|---|----|-------|---|----|
| | Barley | | | Wheat | | | Barley | | | Wheat | | |
| Seed treatment | | | | | | | | | | | | |
| Charter 2.5 | 12.6 | ab | * | 6.7 | a | * | 11.2 | a | * | 2.9 | a | * |
| Dividend XL RTA | 23.2 | ab | * | 5.5 | a | * | 18.5 | a | * | 9.9 | a | * |
| Gemini | < 0.1 | b | ns | 7.1 | a | * | 11.4 | a | * | 1.2 | a | ns |
| Maxim 480 FS | 15.1 | ab | * | < 0.1 | a | ns | 2.5 | a | * | 3.0 | a | * |
| Raxil 250 FL | 4.6 | ab | * | 2.8 | a | * | 3.9 | a | * | 0.7 | a | ns |
| Raxil MD | 3.0 | ab | * | < 0.1 | a | ns | 8.0 | a | * | 1.3 | a | ns |
| Raxil T | 8.2 | ab | * | < 0.1 | a | ns | 2.1 | a | * | 5.1 | a | * |
| Vitaflo 280 (low) | 28.4 | a | * | < 0.1 | a | ns | 2.5 | a | * | 3.6 | a | * |
| Vitaflo 280 (high) | 12.5 | ab | * | < 0.1 | a | ns | 1.0 | a | ns | 2.5 | a | * |
| BASF3 | 11.8 | ab | * | 4.3 | a | * | 2.1 | a | * | 8.4 | a | * |
| BASF4 | 2.1 | ab | * | 4.4 | a | * | 10.3 | a | * | 3.7 | a | * |
| Bayer1 | 10.7 | ab | * | < 0.1 | a | ns | 5.8 | a | * | 5.7 | a | * |
| Untreated infected | 3.7 | ab | * | < 0.1 | a | ns | 13.1 | a | * | 2.1 | a | * |
| Untreated uninfected | 25.2 | ab | * | 4.2 | a | * | 9.5 | a | * | 2.3 | a | * |

F. culmorum

| Location*plant species*seed treatment | Indian Head | | | | | | Redvers | | | | | |
|---------------------------------------|-------------|---|----|-------|---|----|---------|---|----|-------|---|----|
| | Barley | | | Wheat | | | Barley | | | Wheat | | |
| Seed treatment | | | | | | | | | | | | |
| Charter 2.5 | < 0.1 | a | ns | 1.3 | a | * | 0.6 | a | ns | 1.7 | a | * |
| Dividend XL RTA | 2.4 | a | * | < 0.1 | a | ns | < 0.1 | a | ns | < 0.1 | a | ns |
| Gemini | 1.8 | a | * | 1.1 | a | ns | < 0.1 | a | ns | 2.1 | a | * |
| Maxim 480 FS | < 0.1 | a | ns | < 0.1 | a | ns | 0.7 | a | ns | 4.9 | a | * |

| | | | | | | | | | | | | |
|----------------------|-------|---|----|-------|---|----|-------|---|----|-------|---|----|
| Raxil 250 FL | < 0.1 | a | ns | 3.0 | a | * | < 0.1 | a | ns | 0.4 | a | ns |
| Raxil MD | < 0.1 | a | ns | 3.1 | a | * | 2.5 | a | * | < 0.1 | a | ns |
| Raxil T | < 0.1 | a | ns | < 0.1 | a | ns | < 0.1 | a | ns | 0.4 | a | ns |
| VitaFlo 280 (low) | < 0.1 | a | ns | 1.0 | a | ns | 0.9 | a | ns | < 0.1 | a | ns |
| VitaFlo 280 (high) | < 0.1 | a | ns | 2.3 | a | * | < 0.1 | a | ns | 3.8 | a | * |
| BASF3 | < 0.1 | a | ns | < 0.1 | a | ns | < 0.1 | a | ns | < 0.1 | a | ns |
| BASF4 | < 0.1 | a | ns | < 0.1 | a | ns | 1.6 | a | * | 2.2 | a | * |
| Bayer1 | 1.8 | a | * | < 0.1 | a | ns | 1.3 | a | * | < 0.1 | a | ns |
| Untreated infected | < 0.1 | a | ns | 3.6 | a | * | < 0.1 | a | ns | < 0.1 | a | ns |
| Untreated uninfected | 4.1 | a | * | 3.6 | a | * | < 0.1 | a | ns | 8.5 | a | * |

F. equiseti

Location*plant species

| Plant species | Indian Head | | | Redvers | | |
|---------------|-------------|---|---|---------|----|---|
| Barley | 3.4 | b | * | 4.2 | ab | * |
| Common wheat | 2.1 | b | * | 7.4 | a | * |

Plant species*seed treatment

| Seed treatment | Barley | | | Wheat | | |
|----------------------|--------|---|---|-------|---|----|
| Charter 2.5 | 4.8 | a | * | 5.8 | a | * |
| Dividend XL RTA | 1.7 | a | * | 12.0 | a | * |
| Gemini | 2.5 | a | * | 6.8 | a | * |
| Maxim 480 FS | 2.4 | a | * | 3.0 | a | * |
| Raxil 250 FL | 4.3 | a | * | 3.2 | a | * |
| Raxil MD | 1.5 | a | * | 5.4 | a | * |
| Raxil T | 6.8 | a | * | 0.6 | a | ns |
| VitaFlo 280 (low) | 5.5 | a | * | 2.8 | a | * |
| VitaFlo 280 (high) | 1.5 | a | * | 6.2 | a | * |
| BASF3 | 10.2 | a | * | 1.0 | a | ns |
| BASF4 | 4.2 | a | * | 1.1 | a | ns |
| Bayer1 | 9.8 | a | * | 6.7 | a | * |
| Untreated infected | 5.8 | a | * | 5.5 | a | * |
| Untreated uninfected | 4.9 | a | * | 3.3 | a | * |

F. graminearum

Location*plant species*seed treatment

| Seed treatment | Indian Head | | | Redvers | | |
|----------------------|-------------|---|-------|---------|----|-------|
| | Barley | | Wheat | Barley | | Wheat |
| Charter 2.5 | 2.9 | a | * | 21.1 | ab | * |
| Dividend XL RTA | 2.4 | a | * | 4.1 | a | * |
| Gemini | 2.5 | a | * | 5.2 | a | * |
| Maxim 480 FS | < 0.1 | a | ns | 9.3 | ab | * |
| Raxil 250 FL | 2.1 | a | * | < 0.1 | a | ns |
| Raxil MD | 1.5 | a | ns | 15.6 | ab | * |
| Raxil T | 2.4 | a | * | < 0.1 | a | ns |
| VitaFlo 280 (low) | 8.1 | a | * | 5.5 | ab | * |
| VitaFlo 280 (high) | < 0.1 | a | ns | 6.5 | ab | * |
| BASF3 | 2.5 | a | * | 2.1 | a | * |
| BASF4 | 3.6 | a | * | 1.1 | a | ns |
| Bayer1 | 3.7 | a | * | 3.2 | a | * |
| Untreated infected | < 0.1 | a | ns | 22.2 | a | * |
| Untreated uninfected | < 0.1 | a | ns | 19.7 | ab | * |
| | | | | 1.4 | a | ns |
| | | | | 7.1 | ab | * |
| | | | | 3.6 | a | * |
| | | | | 7.0 | ab | * |
| | | | | 0.9 | a | ns |
| | | | | 10.1 | ab | * |
| | | | | 5.4 | a | * |
| | | | | 13.7 | ab | * |
| | | | | < 0.1 | a | ns |
| | | | | < 0.1 | b | ns |

F. oxysporum

Location*plant species*seed treatment

| Seed treatment | Indian Head | | | | Redvers | | | |
|----------------------|-------------|------|-------|------|---------|------|-------|------|
| | Barley | | Wheat | | Barley | | Wheat | |
| Charter 2.5 | < 0.1 | a ns | 5.4 | a * | 10.4 | a * | 1.1 | a ns |
| Dividend XL RTA | 3.9 | a * | < 0.1 | a ns | 19.4 | a * | 5.4 | a * |
| Gemini | 2.2 | a * | < 0.1 | a ns | 11.7 | a * | 3.3 | a * |
| Maxim 480 FS | 4.3 | a * | < 0.1 | a ns | 19.6 | a * | 7.3 | a * |
| Raxil 250 FL | 2.5 | a * | 3.8 | a * | 1.9 | a * | 4.4 | a * |
| Raxil MD | < 0.1 | a ns | 3.0 | a * | 3.9 | a * | 3.6 | a * |
| Raxil T | < 0.1 | a ns | < 0.1 | a ns | 10.9 | a * | 2.6 | a * |
| Vitaflor 280 (low) | < 0.1 | a ns | < 0.1 | a ns | 1.6 | a ns | 3.1 | a * |
| Vitaflor 280 (high) | < 0.1 | a ns | < 0.1 | a ns | 7.3 | a * | 4.0 | a * |
| BASF3 | 3.3 | a * | 13.3 | a * | 12.8 | a * | 3.5 | a * |
| BASF4 | < 0.1 | a ns | < 0.1 | a ns | 15.1 | a * | 7.6 | a * |
| Bayer1 | < 0.1 | a ns | < 0.1 | a ns | 5.5 | a * | 0.1 | a ns |
| Untreated infected | < 0.1 | a ns | < 0.1 | a ns | 1.9 | a * | 4.8 | a * |
| Untreated uninfected | < 0.1 | a ns | < 0.1 | a ns | 7.6 | a * | 6.9 | a * |

Microdochium bolleyi**Location*seed treatment**

| Seed treatment | Indian Head | | Redvers | |
|----------------------|-------------|-----|---------|-----|
| Charter 2.5 | 9.9 | a * | 16.8 | a * |
| Dividend XL RTA | 5.0 | a * | 25.5 | a * |
| Gemini | 15.4 | a * | 23.6 | a * |
| Maxim 480 FS | 12.9 | a * | 18.1 | a * |
| Raxil 250 FL | 14.7 | a * | 19.7 | a * |
| Raxil MD | 7.9 | a * | 24.1 | a * |
| Raxil T | 2.2 | a * | 18.6 | a * |
| Vitaflor 280 (low) | 6.8 | a * | 19.9 | a * |
| Vitaflor 280 (high) | 19.9 | a * | 20.5 | a * |
| BASF3 | 1.5 | a * | 17.2 | a * |
| BASF4 | 6.2 | a * | 12.8 | a * |
| Bayer1 | 11.0 | a * | 13.5 | a * |
| Untreated infected | 7.0 | a * | 22.0 | a * |
| Untreated uninfected | 2.9 | a * | 31.4 | a * |

Plant species*seed treatment

| Seed treatment | Barley | | Wheat | |
|----------------------|--------|-----|-------|-----|
| Charter 2.5 | 10.3 | a * | 16.1 | a * |
| Dividend XL RTA | 7.4 | a * | 17.8 | a * |
| Gemini | 13.3 | a * | 27.2 | a * |
| Maxim 480 FS | 9.2 | a * | 25.3 | a * |
| Raxil 250 FL | 7.8 | a * | 35.7 | a * |
| Raxil MD | 6.1 | a * | 30.5 | a * |
| Raxil T | 2.0 | a * | 19.8 | a * |
| Vitaflor 280 (low) | 6.0 | a * | 22.2 | a * |
| Vitaflor 280 (high) | 13.5 | a * | 29.9 | a * |
| BASF3 | 7.8 | a * | 4.2 | a * |
| BASF4 | 5.1 | a * | 15.3 | a * |
| Bayer1 | 8.0 | a * | 18.3 | a * |
| Untreated infected | 12.4 | a * | 12.7 | a * |
| Untreated uninfected | 11.8 | a * | 8.8 | a * |

Means in a column for an effect or an interaction followed by the same letter are not significantly different ($P < 0.05$).

*, value is significantly different from 0; ns, value is not significantly different from 0.

Table 15. Emergence and growth of plants derived from *Fusarium*-infected seed of the common wheat cultivar Superb, in a controlled-environment trial.

| Seed treatment | Days to initiation of emergence | Days to half seedlings emerged | Days to all seedlings emerged | Total seedlings emerged | Leaves per plant 10 d after seeding | Total no. of plants alive at harvest | Dead plants at harvest | Total tillers at harvest | Growth stage at harvest |
|----------------------|------------------------------------|-----------------------------------|----------------------------------|----------------------------|--|---|---------------------------|-----------------------------|----------------------------|
| Charter 2.5 | 6.4 | 7.2 | 8.5 | 3.0 bc | 1.8 | 2.3 cd | 0.7 ab | 4.8 | 2.0 cd |
| Dividend XL | 6.8 | 6.9 | 8.4 | 2.7 bc | 1.8 | 2.5 b-d | 0.2 c | 4.9 | 2.3 a-c |
| Gemini | 6.7 | 7.4 | 8.8 | 3.5 b | 2.0 | 3.3 bc | 0.2 c | 4.3 | 2.4 a-c |
| Maxim 480 FS | 7.0 | 7.1 | 8.1 | 2.2 cd | 1.9 | 2.1 de | 0.1 c | 4.6 | 2.6 ab |
| Raxil MD | 6.5 | 7.0 | 9.2 | 3.4 b | 1.8 | 3.1 b-d | 0.3 bc | 4.8 | 2.2 a-c |
| Raxil T | 6.6 | 7.8 | 9.7 | 3.4 b | 2.0 | 2.7 b-d | 0.7 ab | 4.6 | 1.7 d |
| Vitaflo 280 | 6.1 | 6.9 | 8.5 | 3.3 bc | 1.9 | 2.3 cd | 1.0 a | 5.1 | 1.5 d |
| Bayer I | 6.4 | 7.2 | 9.6 | 3.6 b | 2.0 | 3.4 b | 0.2 c | 4.5 | 2.2 bc |
| Untreated infected | 7.2 | 7.3 | 8.1 | 1.2 d | 1.8 | 1.1 e | 0.1 c | 4.4 | 2.2 a-c |
| Untreated uninfected | 6.3 | 6.2 | 8.3 | 5.0 a | 2.2 | 5.0 a | 0.0 c | 5.8 | 2.7 a |
| P (0.05) | NS | NS | NS | 0.0001 | NS | 0.0001 | 0.0005 | NS | 0.0001 |
| LSD (0.05) | na | na | na | 1.1 | na | 1.1 | 0.5 | na | 0.5 |

Means in a column for an effect or an interaction followed by the same letter are not significantly different ($P < 0.05$).

Table 16. Common root rot and crown rot severity, and percent fungal isolation from discolored subcrown internodes of plants alive at harvest, derived from *Fusarium* -infected seed of the common wheat cultivar Superb, in a controlled-environment trial.

| Seed treatment | Subcrown internodes | | | Crowns | | | |
|----------------------|---------------------------------|---------------------------------|-------------------------------|---------------------------------|--------------------------------|---------------------------------|-------------------------------|
| | discoloration severity (0-4) | <i>F.</i> <i>graminearum</i> | Total <i>Fusarium</i> spp. | discoloration severity (0-4) | discoloration up stem (1-4) | <i>F.</i> <i>graminearum</i> | Total <i>Fusarium</i> spp. |
| | Mean (%) | | | | | | |
| Charter 2.5 | 1.6 a | 0.2 | 0.3 | 1.1 ab | 0.9 a | 0.3 ab | 0.3 bc |
| Dividend XL | 1.1 a | 0.2 | 0.6 | 1.2 ab | 1.0 a | 0.3 ab | 0.4 a-c |
| Gemini | 1.5 a | 0.3 | 0.4 | 1.1 ab | 0.8 a | 0.4 a | 0.5 ab |
| Maxim 480 FS | 1.3 a | 0.2 | 0.3 | 1.1 ab | 0.9 a | 0.5 a | 0.6 a |
| Raxil MD | 1.2 a | 0.1 | 0.4 | 0.7 bc | 0.7 a | 0.2 ab | 0.3 bc |
| Raxil T | 1.1 a | 0.2 | 0.5 | 0.8 ab | 0.7 a | 0.3 ab | 0.4 ab |
| Vitaflo 280 | 1.5 a | 0.1 | 0.3 | 1.4 a | 1.0 a | 0.5 a | 0.5 ab |
| Bayer1 | 0.9 ab | 0.3 | 0.5 | 1.0 ab | 0.9 a | 0.3 ab | 0.4 a-c |
| Untreated infected | 1.6 a | 0.1 | 0.4 | 1.2 ab | 1.2 a | 0.4 a | 0.5 ab |
| Untreated uninfected | 0.2 b | 0.0 | 0.2 | 0.1 c | 0.1 b | 0.0 b | 0.1 c |
| P (0.05) | NS (0.076) | NS | NS | 0.014 | 0.029 | NS(0.083) | NS(0.052) |
| LSD (0.05) | 1.0 | na | na | 0.7 | 0.6 | 0.3 | 0.4 |

Means in a column for an effect or an interaction followed by the same letter are not significantly different ($P < 0.05$).

Impacts of Crop Production Factors on Common Root Rot of Barley in Eastern Saskatchewan

M. R. Fernandez,* R. P. Zentner, R. M. DePauw, D. Gehl, and F. C. Stevenson

ABSTRACT

Fusarium head blight (FHB) in barley (*Hordeum vulgare* L.) has been spreading on the Canadian Prairies for the last decade. *Fusarium* spp. causing FHB can also cause crown and root rot of cereal crops. It is therefore of interest to determine the impact of agronomic practices on fungal populations associated with root rot of barley. From 1999 to 2001, 137 barley crops were sampled in eastern Saskatchewan for severity of subcrown internode discoloration and percentage isolation of fungi. *Cochliobolus sativus* was the most commonly isolated fungus, whereas the most commonly isolated *Fusarium* spp. included the FHB pathogens *F. avenaceum*, *F. culmorum*, and *F. graminearum*. Discoloration caused by *C. sativus* was favored by conventional-till, whereas *Fusarium* spp. increased in reduced tillage systems. Barley grown after a cereal–summer fallow sequence under conventional- or minimum-till had increased levels of *C. sativus*. *Fusarium* spp. were most affected by the previously grown crop(s); they were more common in barley grown after a noncereal than a cereal, and after two noncereals, or a noncereal alternated with summer fallow. Previous glyphosate applications were associated with lower *C. sativus* and higher *Fusarium* spp. levels in barley grown under minimum-till management. This suggests changes in fungal communities; however, the mechanism(s) responsible for these changes in fungal levels are not known. Increased infection of ground and underground tissue by FHB pathogens may contribute to its development in succeeding cereal crops. Therefore, measures aimed at reducing root and crown infections by *Fusarium* spp. may also help reduce FHB development.

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Abbreviations: C, cereal; CRR, common root rot; CRR1, common root rot index; CT, conventional-till; F, summer fallow; FHB, *Fusarium* head blight; MT, minimum-till; NC, noncereal; SI, subcrown internode; ZT, zero-till.

COMMON ROOT ROT (CRR) is an important and widespread disease of cereal crops in the Canadian Prairies (Fernandez and Jefferson, 2004) that can cause significant grain yield losses (Tinline and Ledingham, 1979). In general, barley is considered to be more susceptible to CRR caused by *Cochliobolus sativus* (Ito & Kuribayashi) Drechs. Ex Dast. [anamorph *Bipolaris sorokiniana* (Sacc.) Shoemaker] than wheat (*Triticum aestivum* L.) (Piening et al., 1976). However, root and crown rot of barley can also be caused by *Fusarium* spp. In Quebec, Pua et al. (1985) isolated *Fusarium* spp. from diseased subcrown internodes (SIs) of barley at levels similar to or lower than those of *C. sativus* but did not identify them to species level. In central Alberta, *F. culmorum* (W.G. Smith) Sacc. was isolated from SIs of barley (Piening and Orr, 1988). In studies conducted in Prince Edward Island, *F. avenaceum* (Fr.:Fr.) Sacc. (teleomorph *Gibberella avenacea* Cook) was one of the main root pathogens of barley (Sturz and Carter, 1995), whereas *F. avenaceum* and *F. graminearum* Schwabe [teleomorph *G. zeae* (Schwein.) Petch] (or *F. pseudograminearum* O'Donnell et

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T. Aoki) were among the most common *Fusarium* spp. isolated from barley crowns (Sturz and Johnston, 1985). Windels and Wiersma (1992) reported *F. graminearum* as the most common *Fusarium* species isolated from SIs of barley in Minnesota and *F. avenaceum* as one of the least commonly isolated species, whereas *Fusarium* spp. were found to be more prevalent than *C. sativus* in South Australia (Fedel-Moen and Harris, 1987).

Fusarium head blight (FHB) in barley has been established in the eastern Prairies for the last decade (Tekauz et al., 2000). *Fusarium graminearum* and *F. avenaceum* were the most common FHB pathogens of barley crops grown in 2005 in Manitoba (Tekauz et al., 2006), whereas *F. avenaceum* has consistently been one of the most commonly isolated species from FHB-affected barley crops in Saskatchewan, where this disease has occurred at lower levels than in eastern regions of the Prairies (Pearse et al., 2006). Because of concerns regarding increasing FHB development on the eastern Canadian Prairies and its apparent spread westward, it is essential to put in place a comprehensive strategy to stop or reduce the rate of spread of this disease and to decrease the damage it has been causing to the barley industry in areas where it is already well established. To this end, there is a need for more information on the epidemiology of FHB in Saskatchewan so that the risk factors associated with its spread and development can be better understood. A comprehensive approach needs to include an examination of crown and root rot caused by *Fusarium* spp. in this region. *Fusarium* infection of ground and underground barley tissue could result in higher fungal levels in crop residues and thus be a source of inoculum for spike infection and fungal carryover from one season to the next. A better understanding of all factors affecting *Fusarium* inoculum and infection of barley tissue may help in devising a more effective strategy aimed at reducing inoculum levels and disease development and preventing the further spread of important cereal diseases caused by *Fusarium* spp.

Few studies have been conducted on the impact of agronomic practices, such as tillage system and crop rotation, on CRR of barley and associated fungal populations. Windels and Wiersma (1992) reported higher levels of *C. sativus*, and lower levels of *F. avenaceum* and *F. graminearum*, going from less to more intensive tillage. Common root rot in barley decreased when grown after 2 yr of oilseed crops (Conner et al., 1996; Piening and Orr, 1988), whereas barley grown following summer fallow had higher CRR, mostly attributed to *C. sativus* (Piening et al., 1976), and lower levels of *Fusarium* spp. in crowns than when grown following a crop (Sturz and Johnston, 1985). In recent years, Canadian Prairie producers have become more reliant on noncereal crops, including oilseeds and pulses, and have increasingly adopted more continuous cropping and greater use of conservation tillage practices. It is therefore

of interest to determine the impact of currently popular cropping sequences and tillage systems on fungal populations in underground tissue of barley crops.

The objective of the present study was to determine CRR levels in barley crops grown in eastern Saskatchewan, identify and quantify fungal species from infected tissue, and determine the association between disease and fungal levels and crop production systems, with the aim of determining what crop production factors might reduce *Fusarium* infections in barley crops.

MATERIALS AND METHODS

Description of Fields Sampled

Commercial fields (experimental units) were selected at random within Crop Districts 1B and 5A in southeast and east-central Saskatchewan to represent the most common cropping practices in the area. A description of the study area was provided by Fernandez et al. (2005). A total of 137 barley crops were sampled from 1999 to 2001 for severity of SI discoloration and percentage isolation of fungi. There were 26 crops in 1999, 61 in 2000, and 50 in 2001. Of these, 63% were six-rowed and the rest were two-rowed cultivars. Among the six-rowed cultivars, the most common was Excel (41% of all six-rowed barley crops) followed by Robust (29%), whereas among the two-rowed cultivars, the most common were Harrington (25% of all two-rowed barley crops) and AC Metcalfe (22%).

Sampling for Common Root Rot Evaluation

In late July to early August, a total of 35 to 50 plants at approximately the mid-milk to dough stage (growth stages 75–83, Zadoks et al., 1974) were carefully pulled from at least 15 spots randomly selected within each field following a large circular pattern, starting about 40 m from the edge of the field. Each plant sampled had an SI of at least 2 cm. Samples were washed under tap water, thoroughly dried, and kept at room temperature until analyzed. Subcrown internodes were carefully removed and rated for extent of brown to black discoloration on a 0 to 3 scale (0 = no discoloration, 1 = slight with <25% of the surface area discolored, 2 = moderate with 25 to 50% discoloration, and 3 = severe with >50% discoloration (Ledingham et al., 1973). An SI discoloration index (common root rot index; CRR_I) was calculated for each field based on the incidence and severity of the discoloration, as follows: [(Category value × plants in category)/total number of plants sampled] × 100. The most discolored segment (about 1 cm²) of each SI was then excised, surface-disinfested for 1 min in 0.6% NaOCl, and rinsed in sterile distilled water twice. Tissue pieces were then plated on modified potato dextrose agar (Burgess et al., 1988; Fernandez and Chen, 2005) and incubated under cool-white fluorescent and near-UV lights (16 h light/8 h dark) (light intensity of 110 μmol s⁻¹ m⁻²) for about 7 d. Fungi growing out of the tissue pieces were identified on the basis of colony and spore morphology using descriptions and keys in Samson et al. (2002) and Watanabe (2002). All isolates identified as *F. graminearum* produced perithecia in culture. Percentage isolation of each fungus was calculated based on the total number of isolates in each field.

Categorization of Barley Crops/Fields into Crop Production Factors

At the end of the growing season, each producer supplied information regarding grain yield and the agronomic practices related to the crop(s) sampled, such as cultivar, crop history, tillage method, and pesticide use. This information was used to categorize the crops/fields according to crop production factors, which was then used for further analysis to determine the association of these factors with CRRI and percentage fungal isolation.

For tillage system, fields were categorized on the basis of the total number of tillage operations performed in the previous 3 yr. Fields under conventional till (CT) had a total of seven or more tillage operations, and those under minimum till (MT) had one to six operations (i.e., up to two tillage passes per year). There were no tillage operations in fields under zero-till (ZT) management during the same period of time. Residue cover was not estimated for any field. The average number of tillage operations in the previous 3 yr was 3.4 for fields under MT and 8.2 for fields under CT. Herbicide applications were categorized according to whether the fields had received any of the Group 1, 2, 4, or 9 herbicides (Saskatchewan Agriculture and Food, 2006) in the previous 18 mo.

For previously grown crops, fields were categorized according to the crop, if any, grown the previous year: cereal, oilseed, pulse, or summer fallow. Fields were also categorized according to the crops, if any, grown the previous 2 yr, regardless of the order in the sequence: two cereal (C) crops (C–C), two noncereal (NC) crops (NC–NC), a cereal and a noncereal crop (C–NC), or summer fallow (F) and a crop (C–F or NC–F). In addition, fields were also categorized according to whether the first crop in the C–NC sequence was a cereal or an oilseed (O) crop (i.e., C*–NC for cereal as the first crop, O*–C for oilseed as the first crop).

The most common cropping practice the year before barley was to grow oilseed crops (42% of all fields), namely, canola (*Brassica* spp.) (35%) and flax (*Linum usitatissimum* L.) (6%). This was followed by cereal crops (38%), the most common of which were common wheat (*Triticum aestivum* L.) and durum wheat (*T. turgidum* L. var. *durum*) (15%), barley (13%), and oat (*Avena sativa* L.) (9%), followed by summer fallow (11%), and pulse crops (8% of all fields). The most common cropping practice 2 yr previous to the sampling was to grow cereal crops, namely, common and durum wheat (29% of all fields), barley (12%), or oat (9%). This was followed by oilseed crops, canola (20%) or flax (7%), summer fallow (15%), and pulse crops (4% of the fields).

Most barley crops grown after a cereal or oilseed crop were under MT management (60–65%), those after a pulse crop were under either MT (33%) or ZT (42%), and most crops grown after summer fallow were under CT (44%) or MT (56%). When fields were categorized according to the two previously grown crops, most barley crops grown after C–C or C–NC were under MT (61–75%), most grown after NC–NC were under ZT (64%) or MT (36%), and most grown after C–F or NC–F were under MT (53–60%) or CT (35–47%).

Based on the N fertilizer input in the spring and/or previous fall, on average, barley crops preceded by a cereal or an oilseed crop received the highest N rate (mean of 65–66 kg ha⁻¹), followed by those grown after a pulse crop (56 kg ha⁻¹),

while crops grown after summer fallow received the least N (33 kg ha⁻¹). Based on the categorization of fields according to the previous two crops, barley grown after C–NC received the most N (mean of 69 kg ha⁻¹), followed by C–C, NC–NC, and NC–F (53–55 kg ha⁻¹), with crops grown after C–F receiving the least N (36 kg ha⁻¹). No soil N testing was performed on any of the fields sampled.

Statistical Analyses

Disease-, fungal- and grain yield-related responses were compared with SAS's SURVEYREG procedure, and means were estimated with the SURVEYMEANS procedure (SAS Institute, 1999). The analysis included the barley crop type (two- or six-rowed) cross-classified with previous crop(s) or tillage systems. Data collected for each year were assumed to be stratum for the analysis. The rate at which each stratum was sampled was based on the actual number of samples divided by the total number of barley producers in Saskatchewan (assumed to be one half of 11 130 for barley; derived from <http://www.statcan.ca/english/Pgdb/agrc22i.htm>). Treatment effects were declared significant at $P \leq 0.10$. Contrasts were performed among cropping sequences and tillage systems for total disease level (CRRI) and percentage of the most commonly isolated fungi. Only the contrasts that showed significant effects for at least one of the fungi or CRRI are presented in the tables. Fungi for which no significant effects of previous crop(s) or tillage method were determined are also not included in the tables.

The impact of previous application of herbicide Groups 1, 2, 4, and 9 in each of the tillage systems was further examined for disease-, fungal- and grain yield-related variables. Differences among the herbicide treatments (applied: yes/no) for the 18-mo data were analyzed separately with SAS's SURVEYREG procedure, and means were estimated with the SURVEYMEANS procedure (SAS Institute, 1999). Effects were again declared significant at $P \leq 0.10$.

RESULTS

Common Root Rot Levels and Fungal Isolations

In all 3 yr, the fungus with the highest probability of occurrence and mean percentage isolation in SIs of barley was *C. sativus*, followed by *Microdochium bolleyi* (R. Sprague) de Hoog & Hermanides-Nijhof (Table 1). *Fusarium* spp. constituted the second most common genus; among these, the most common species were *F. equiseti* (Corda) Sacc. and *F. avenaceum*. These were followed by *F. culmorum*, *F. graminearum*, and *F. acuminatum* Ellis & Everh. *Fusarium poae* (Peck) Wollenweb. and *F. sporotrichioides* Sherb. were found in <10% of the fields at a mean percentage isolation of <1%. Other *Fusarium* spp. isolated only occasionally included *F. pseudograminearum* and *F. oxysporum* Schlecht.:Fr. Other fungal species frequently isolated were *Alternaria* spp., *Rhizoctonia* spp., and *Stemphylium* spp.

The isolation of fungi from SI lesions rated as moderately severe or severe reflected their overall relative occurrence and percentage isolation (Tables 1 and 2). On average, for 2000 and 2001, out of the total number of

Table 1. Percentage of barley crops in which common root rot (CRR) was observed and fungi were isolated from discolored subcrown internodes (percentage occurrence), and mean CRR index (CRRI) and percentage isolation of fungi in eastern Saskatchewan, 1999–2001.

| Disease/fungus | Percentage occurrence | | | | Mean percentage isolation | | | |
|-----------------------------|-----------------------|------|------|-----------|---------------------------|------|------|-----------|
| | 1999 | 2000 | 2001 | 1999–2001 | 1999 | 2000 | 2001 | 1999–2001 |
| | % | | | | | | | |
| CRR | 100 | 100 | 100 | 100 | – | – | – | – |
| CRRI | – | – | – | – | 1.8 | 1.6 | 1.8 | 1.7 |
| <i>Cochliobolus sativus</i> | 100 | 98 | 100 | 99 | 63.3 | 47.3 | 51.1 | 51.4 |
| <i>Fusarium</i> spp.—total | 95 | 95 | 84 | 91 | 20.0 | 18.2 | 22.5 | 20.1 |
| <i>F. equiseti</i> | 59 | 67 | 65 | 65 | 7.7 | 6.4 | 11.8 | 8.6 |
| <i>F. avenaceum</i> | 36 | 61 | 53 | 54 | 4.1 | 5.2 | 4.6 | 4.8 |
| <i>F. culmorum</i> | 27 | 36 | 14 | 27 | 4.4 | 3.9 | 1.8 | 3.2 |
| <i>F. acuminatum</i> | 18 | 21 | 2 | 14 | 1.8 | 1.4 | 0.1 | 1.0 |
| <i>F. graminearum</i> | 9 | 10 | 33 | 18 | 0.6 | 0.6 | 3.5 | 1.7 |
| <i>F. poae</i> | 0 | 0 | 10 | 4 | 0.0 | 0.0 | 0.4 | 0.2 |
| <i>F. sporotrichioides</i> | 0 | 11 | 8 | 8 | 0.0 | 0.7 | 0.3 | 0.4 |
| <i>Alternaria</i> spp. | 18 | 21 | 51 | 32 | 1.9 | 2.3 | 5.5 | 3.4 |
| <i>Microdochium bolleyi</i> | 55 | 95 | 55 | 73 | 5.5 | 17.1 | 5.4 | 10.8 |
| <i>Rhizoctonia</i> spp. | 9 | 23 | 29 | 23 | 0.7 | 1.7 | 1.9 | 1.6 |
| <i>Stemphylium</i> spp. | 50 | 62 | 20 | 45 | 4.0 | 6.4 | 1.5 | 4.2 |

Table 2. Percentage of most common fungal isolates in discolored subcrown internodes based on total number of isolates, and according to discoloration severity category, for barley crops sampled in eastern Saskatchewan, 2000 and 2001.

| Fungal species | Discoloration severity category ¹ | 2000 | 2001 |
|-----------------------------|--|-----------------|------|
| | | % | |
| <i>Cochliobolus sativus</i> | S | 51 ² | 61 |
| | MS | 53 | 57 |
| <i>Fusarium avenaceum</i> | S | 9 | 6 |
| | MS | 4 | 3 |
| <i>F. culmorum</i> | S | 7 | 2 |
| | MS | 4 | 2 |
| <i>F. equiseti</i> | S | 7 | 8 |
| | MS | 10 | 11 |
| <i>F. graminearum</i> | S | 1 | 8 |
| | MS | 2 | 4 |
| <i>Microdochium bolleyi</i> | S | 18 | 5 |
| | MS | 15 | 5 |

¹S, severe lesions; MS, moderately severe lesions, in subcrown internodes of barley.

²For each fungus, the mean percentage of isolates in S or MS lesions is based on the total number of isolates of all fungal species from S or MS lesions, respectively.

fungal isolates that grew out of SI lesions rated as severe or moderately severe, more than 50% were *C. sativus*, followed by *M. bolleyi* at an average of over 10% for both years. The most commonly isolated *Fusarium* spp. from these lesions were *F. avenaceum* and *F. equiseti*, followed by *F. culmorum* and *F. graminearum*.

The occurrence of more than one fungal species in a lesion was observed often. The species that occurred most frequently together with other fungi in moderately severe

or severe lesions were *C. sativus* (41% of all fungal isolations), *M. bolleyi* (17%), and *F. equiseti* (18%). Furthermore, *C. sativus* was isolated from moderately severe or severe lesions more frequently with *F. equiseti* and *M. bolleyi* (mean of 38% and 28%, respectively, of all *C. sativus* isolations) than with any other fungus (data for other fungal combinations not presented).

Effects of Crop Production Factors on Common Root Rot and Fungal Isolations

The CRRI was significant for crop type, being higher in two- than in six-rowed barley cultivars (Table 3). However, there was little difference among crop types for percentage fungal isolations. *Fusarium culmorum* was the only species present at significantly higher levels in six-rowed barley, whereas *F. equiseti* was isolated most frequently from two-rowed barley. There were no significant interactions of crop type with previous crop or summer fallow, whereas there were some significant interactions of previous 2-yr cropping sequence with crop type;

however, these did not result in changes in rank order. Because of the small sample size for some of the cropping sequences for two- and/or six-rowed barley, only the analysis based on all crops is presented.

There was not much effect of previous crop or 2-yr cropping sequence on the overall CRRI (Table 3). The type of crop(s) grown the previous year appeared to affect isolations of *C. sativus* more than a previous year of summer fallow, with barley grown after a cereal crop having higher levels of *C. sativus* than when grown after an oilseed, but not when grown after a pulse crop. However, a year of summer fallow alternated with a cereal crop (C–F) resulted in significantly higher levels of this fungus than when grown after other sequences, except for C–NC.

Overall, growing a noncereal crop the previous year resulted in higher relative levels of *Fusarium* spp. in barley SIs than growing a cereal crop, with barley grown after a pulse crop having the highest levels (Table 3). *Fusarium* spp. were also most frequently isolated when no cereal was present in either of the previous 2 yr (i.e., NC–NC or NC–F). Regarding the individual *Fusarium* spp., there was also a tendency for isolation of *F. avenaceum* from SIs to be the lowest in barley grown after a cereal crop than after a noncereal crop, whereas the highest percent isolation of *F. culmorum* occurred when barley was grown after a pulse crop. The latter fungus was the only *Fusarium* species present at significantly lower levels when barley was grown after summer fallow than after any crop, especially pulses, and was also lowest after C–F. In contrast, *F. equiseti* tended to be more commonly isolated after sum-

Table 3. Effect of crop type and previous crop(s) or summer fallow on the common root rot index (CRRl) and percentage isolation of the most common fungi isolated from subcrown internodes, for barley crops sampled in eastern Saskatchewan, 1999–2001.

| Effect, contrast | Number of crops | CRRl | Cs [†] | Fus spp. | Fav | Fc | Fe | Fg | Mb |
|--|-----------------|-------------|-----------------|------------|-----------|------------|------------|-----------|------------|
| <hr/> | | | | | | | | | |
| Crop type (two- or six-rowed) | | 0.001 | 0.886 | 0.743 | 0.500 | 0.017 | 0.070 | 0.749 | 0.981 |
| <hr/> | | | | | | | | | |
| Mean % (SE) | | | | | | | | | |
| Two-rowed | 50 | 2.0 (0.1) | 54.5 (2.8) | 21.7 (2.0) | 4.9 (0.9) | 1.5 (0.4) | 11.0 (1.8) | 1.9 (0.7) | 9.3 (1.3) |
| Six-rowed | 87 | 1.5 (< 0.1) | 49.4 (2.0) | 19.3 (1.7) | 4.8 (0.7) | 4.2 (1.1) | 7.2 (1.0) | 1.6 (0.5) | 11.5 (1.0) |
| <hr/> | | | | | | | | | |
| P value | | | | | | | | | |
| Previous crop | | 0.315 | 0.153 | 0.001 | 0.323 | 0.154 | 0.212 | 0.312 | 0.689 |
| Cereal vs. oilseed or pulse | | 0.981 | 0.297 | 0.001 | 0.152 | 0.032 | 0.612 | 0.092 | 0.242 |
| Cereal vs. oilseed | | 0.395 | 0.076 | 0.008 | 0.208 | 0.979 | 0.249 | 0.124 | 0.357 |
| Cereal vs. pulse | | 0.711 | 0.934 | 0.006 | 0.282 | 0.026 | 0.932 | 0.278 | 0.334 |
| Oilseed vs. pulse | | 0.436 | 0.139 | 0.175 | 0.646 | 0.026 | 0.695 | 0.928 | 0.636 |
| Summer fallow vs. others | | 0.344 | 0.231 | 0.628 | 0.535 | 0.050 | 0.130 | 0.957 | 0.705 |
| <hr/> | | | | | | | | | |
| Mean % (SE) | | | | | | | | | |
| Cereal | 50 | 1.7 (0.1) | 53.7 (2.8) | 14.8 (1.3) | 3.6 (0.6) | 2.2 (0.7) | 7.1 (1.1) | 0.8 (0.3) | 11.8 (1.2) |
| Oilseed | 59 | 1.6 (0.1) | 47.0 (2.6) | 22.1 (2.3) | 5.4 (0.9) | 2.8 (0.9) | 9.0 (1.5) | 2.2 (0.8) | 10.2 (1.2) |
| Pulse | 11 | 1.8 (0.2) | 54.5 (4.0) | 30.5 (5.2) | 6.2 (2.3) | 12.8 (5.3) | 7.7 (5.0) | 2.5 (1.4) | 8.0 (3.2) |
| Summer fallow | 14 | 1.8 (0.1) | 59.1 (4.1) | 23.5 (3.2) | 5.7 (1.8) | 1.7 (1.3) | 12.9 (2.7) | 1.9 (1.4) | 11.8 (2.9) |
| <hr/> | | | | | | | | | |
| P value | | | | | | | | | |
| Previous two crops ² | | 0.617 | 0.001 | 0.002 | 0.903 | 0.006 | 0.000 | 0.944 | 0.002 |
| C–C vs. C–F | | 0.254 | 0.100 | 0.598 | 0.615 | 0.078 | 0.682 | 0.722 | 0.846 |
| C–C vs. NC–NC | | 0.622 | 0.156 | 0.005 | 0.572 | 0.705 | 0.006 | 0.838 | 0.198 |
| C–F vs. NC–F | | 0.490 | 0.058 | 0.315 | 0.826 | 0.049 | 0.470 | 0.565 | 0.043 |
| C–NC vs. C–F | | 0.127 | 0.338 | 0.190 | 0.613 | 0.003 | 0.018 | 0.877 | 0.693 |
| C–NC vs. NC–F | | 0.537 | 0.126 | 0.019 | 0.691 | 0.640 | 0.015 | 0.509 | 0.001 |
| C–NC vs. NC–NC | | 0.521 | 0.000 | 0.000 | 0.512 | 0.875 | 0.000 | 0.543 | 0.494 |
| NC–NC vs. C–F | | 0.480 | 0.001 | 0.027 | 0.396 | 0.267 | 0.013 | 0.601 | 0.467 |
| <hr/> | | | | | | | | | |
| Mean % (SE) | | | | | | | | | |
| C–C | 15 | 1.6 (0.1) | 46.7 (5.6) | 19.9 (2.9) | 4.9 (1.2) | 2.1 (1.0) | 10.6 (2.8) | 1.3 (0.9) | 13.4 (2.2) |
| C–NC | 74 | 1.6 (0.1) | 52.4 (2.2) | 17.6 (1.7) | 4.6 (0.7) | 3.3 (1.0) | 5.6 (0.8) | 1.9 (0.6) | 11.4 (1.1) |
| NC–NC | 11 | 1.6 (0.1) | 45.1 (5.6) | 27.3 (5.1) | 3.8 (1.3) | 5.4 (4.1) | 14.4 (4.2) | 1.1 (0.8) | 10.2 (2.5) |
| C–F | 16 | 1.8 (0.1) | 60.2 (4.0) | 19.0 (2.8) | 4.7 (1.6) | 0.6 (0.4) | 10.3 (1.9) | 2.0 (1.2) | 13.3 (2.7) |
| NC–F | 19 | 1.8 (0.1) | 46.4 (4.2) | 27.9 (4.2) | 5.9 (1.4) | 4.7 (2.1) | 14.8 (3.9) | 1.0 (0.7) | 4.5 (1.3) |
| <hr/> | | | | | | | | | |
| P value | | | | | | | | | |
| Previous two crops, by first crop ³ | | 0.749 | 0.001 | 0.000 | 0.702 | 0.642 | 0.000 | 0.161 | 0.016 |
| C*–NC vs. O*–C | | 0.450 | 0.155 | 0.048 | 0.231 | 0.982 | 0.955 | 0.047 | 0.548 |
| <hr/> | | | | | | | | | |
| Mean % (SE) | | | | | | | | | |
| C*–NC | 32 | 1.7 (0.1) | 55.9 (3.5) | 13.1 (1.4) | 3.1 (0.8) | 2.3 (1.1) | 5.9 (1.0) | 0.5 (0.3) | 11.0 (1.5) |
| O*–C | 36 | 1.6 (0.1) | 49.4 (3.4) | 19.8 (2.9) | 5.4 (1.2) | 2.5 (1.1) | 6.0 (1.4) | 3.0 (1.2) | 12.2 (1.7) |

[†]Cs, *Cochliobolus sativus*; Fus spp., total *Fusarium* spp.; Fav, *F. avenaceum*; Fc, *F. culmorum*; Fe, *F. equiseti*; Fg, *F. graminearum*; Mb, *Microdochium bolleyi*.

²C, cereal; NC, noncereal; F, summer fallow; O, oilseed. Barley crops grouped according to the previous two crops, regardless of the order in the sequence (C–C, C–NC, NC–NC, C–F, and NC–F).

³Barley crops grouped according to first crop in the previous 2-yr crop sequence (e.g., C*–NC for C as the first crop, O*–C for oilseed (O) as the first crop in the C–NC sequence).

mer fallow than after a crop, and its percentage isolation was lowest for cropping sequences that included a cereal and a noncereal crop (C–NC). *Fusarium graminearum* was also present at higher levels in barley crops grown after a noncereal than a cereal crop. Furthermore, when the 2-yr cropping sequence C–NC was further classified by the first crop in the sequence (i.e., C*–NC vs. O*–C), total *Fusarium* spp. and *F. graminearum* were significantly higher

when the previous crop was an oilseed (O*–C) than when it was a cereal (C*–NC). There were few differences for *M. bolleyi* related to previous cropping sequence; this fungus was present at significantly lower levels only after the NC–F sequence.

Analysis of tillage system effects was done for all barley crops regardless of cropping sequence, and also separately for barley preceded by a cereal or an oilseed crop (Table 4).

Table 4. Effect of tillage system on the common root rot index (CRRl) and percentage isolation of the most common fungi isolated from subcrown internodes, for all barley crops and for those preceded by a cereal or an oilseed crop, sampled in eastern Saskatchewan, 1999–2001.

| Effect, Contrast | Number of crops | CRRl | Cs [†] | Fus spp. | Fav | Fc | Fe | Fg | Mb |
|----------------------------|-----------------|-------------|-----------------|------------|-----------|-----------|------------|-----------|------------|
| P value | | | | | | | | | |
| All previous crops | | 0.074 | 0.001 | 0.011 | 0.026 | 0.663 | 0.445 | 0.008 | 0.742 |
| CT vs. MT, ZT [‡] | | 0.016 | 0.000 | 0.006 | 0.012 | 0.907 | 0.187 | 0.005 | 0.391 |
| Mean % (SE) | | | | | | | | | |
| CT | 28 | 1.9 (0.1) | 62.6 (3.2) | 14.6 (2.3) | 3.4 (0.9) | 3.0 (1.3) | 6.3 (1.7) | 0.2 (0.2) | 9.9 (1.9) |
| MT | 82 | 1.6 (< 0.1) | 49.0 (2.1) | 20.5 (1.7) | 4.6 (0.7) | 3.6 (0.9) | 8.5 (1.2) | 2.1 (0.6) | 10.4 (0.9) |
| ZT | 23 | 1.6 (0.1) | 45.8 (3.9) | 25.7 (2.6) | 7.2 (1.4) | 2.2 (1.9) | 11.7 (2.2) | 2.0 (1.0) | 13.4 (2.3) |
| P value | | | | | | | | | |
| Cereal | | 0.138 | 0.045 | 0.000 | 0.114 | 0.004 | 0.258 | 0.178 | 0.583 |
| CT vs. MT, ZT | | 0.513 | 0.032 | 0.001 | 0.090 | 0.227 | 0.070 | 0.058 | 0.091 |
| Mean % (SE) | | | | | | | | | |
| CT | 11 | 1.9 (0.2) | 65.9 (5.5) | 8.4 (1.8) | 1.9 (0.9) | 0.6 (0.4) | 5.1 (1.5) | 0.0 (0.0) | 9.8 (2.7) |
| MT | 31 | 1.6 (0.1) | 50.6 (3.6) | 16.0 (1.8) | 4.1 (0.9) | 3.3 (1.1) | 6.5 (1.4) | 1.3 (0.5) | 11.5 (1.4) |
| ZT | 8 | 1.7 (0.1) | 48.9 (6.4) | 19.0 (2.2) | 3.8 (1.5) | 0.0 (0.0) | 12.3 (2.6) | 0.0 (0.0) | 15.9 (3.9) |
| P value | | | | | | | | | |
| Oilseed | | 0.904 | 0.003 | 0.551 | 0.014 | 0.025 | 0.401 | 0.700 | 0.000 |
| CT vs. MT, ZT | | 0.553 | 0.001 | 0.411 | 0.007 | 0.518 | 0.892 | 0.491 | 0.000 |
| Mean % (SE) | | | | | | | | | |
| CT | 9 | 1.6 (0.1) | 63.8 (5.5) | 17.5 (5.2) | 3.6 (1.7) | 5.0 (3.5) | 6.1 (3.8) | 0.6 (0.6) | 3.3 (1.6) |
| MT | 39 | 1.6 (0.1) | 44.4 (3.1) | 21.9 (3.0) | 5.0 (1.1) | 3.0 (1.1) | 8.5 (1.8) | 2.6 (1.0) | 10.5 (1.4) |
| ZT | 10 | 1.6 (0.1) | 42.0 (6.2) | 27.0 (4.6) | 8.7 (2.0) | 0.2 (0.2) | 13.8 (4.0) | 2.2 (1.5) | 15.3 (3.3) |

[†]Cs, *Cochliobolus sativus*; Fus spp., total *Fusarium* spp.; Fav, *F. avenaceum*; Fc, *F. culmorum*; Fe, *F. equiseti*; Fg, *F. graminearum*; Mb, *Microdochium bolleyi*.

[‡]CT, conventional-till; MT, minimum-till; ZT, zero-till.

For the most part, there was no interaction of tillage system with crop type. The CRRl was higher under CT than reduced tillage for all crops combined. In most cases, *C. sativus* was more common, and *Fusarium* spp. less common, in SIs of barley grown under CT than reduced tillage. This appears to be attributed mostly to higher levels of *F. avenaceum* and *F. graminearum* under reduced tillage. For barley grown after a cereal crop, *F. graminearum* was also found at the highest levels under MT management. *Fusarium culmorum* was isolated at lower levels under ZT than MT and/or CT when barley was grown after a cereal or an oilseed crop. *Fusarium equiseti* was also present at lower levels under CT after a cereal crop, whereas *M. bolleyi* was lowest under CT when barley was grown after a cereal or an oilseed crop.

Herbicide Effects on CRRl and Fungal Isolations

The pattern of herbicide use for the barley crops sampled in this study (1999–2001) was similar to that presented by Fernandez et al. (2007b) for barley crops sampled for FHB in the same area from 1999 to 2002. Overall, there was a higher proportion of barley preceded by summer fallow within the unsprayed fields for Group 1 (29%) than for the other herbicide groups (15–19%), a higher proportion of sprayed fields preceded by an oilseed crop for Group

9 (61%) than for the other groups (42–46%), and a lower proportion of sprayed fields preceded by a cereal crop for Group 9 (27%) than for the other groups (42–44%).

Herbicide analysis (yes/no) was done by tillage system, although sample size was larger for MT- than for CT- or ZT-managed fields (Table 5). For the most part, there was no significant interaction of herbicide group with barley crop type (two- or six-rowed). Further, there was no significant effect of herbicide group on CRRl under MT, with significant effects of Group 4 on CRRl for barley under CT and ZT not being consistent. For all herbicide groups, there were significant negative and positive effects of herbicide applications in the previous 18 mo on the most common fungal isolates. For barley grown under MT, Group 1 herbicides were associated with significantly lower levels of total *Fusarium* spp. and *F. culmorum*, whereas Group 9 herbicides were associated with higher levels of total *Fusarium* spp., *F. culmorum* and *F. graminearum*, but lower levels of *C. sativus*. There was also a tendency for levels of *F. avenaceum* to be higher in sprayed than unsprayed fields for Group 9 but lower for sprayed than unsprayed fields for Group 1 herbicides. The same effects of Group 9 herbicides on fungal isolations observed under MT were in most cases also observed under CT and/or ZT, although in most cases, these were not significant ($P > 0.10$), except for *F. avenaceum* for barley under

Table 5. Effect of herbicide use (previous 18 mo) on the common root rot index (CRRi) and percentage isolation of fungi within each tillage system, for barley crops sampled in eastern Saskatchewan, 1999–2001.

| Herbicide group | Tillage system | Herbicide use | Number of crops | CRRi | Cs [†] | Fus spp. | Fav | Fc | Fe | Fg |
|-----------------|-----------------|-----------------|-----------------|-------------|-----------------|------------|------------|------------|------------|-----------|
| | | | | P value | | | | | | |
| Group 1 | CT [‡] | | | 0.193 | 0.448 | 0.651 | 0.384 | 0.941 | 0.283 | 1.000 |
| | MT | | | 0.371 | 0.899 | 0.020 | 0.205 | 0.074 | 0.232 | 0.880 |
| | ZT | | | 0.520 | 0.821 | 0.713 | 0.763 | 0.554 | 0.622 | 0.110 |
| Group 2 | CT | | | 0.441 | 0.335 | 0.616 | 0.489 | 0.325 | 0.630 | 1.000 |
| | MT | | | 0.142 | 0.435 | 0.290 | 0.682 | 0.754 | 0.424 | 0.397 |
| | ZT | | | 0.412 | 0.284 | 0.034 | 0.375 | 0.278 | 0.140 | 0.528 |
| Group 4 | CT | | | 0.053 | 0.025 | 0.636 | 0.075 | 0.520 | 0.047 | 1.000 |
| | MT | | | 0.436 | 0.860 | 0.722 | 0.879 | 0.277 | 0.839 | 0.260 |
| | ZT | | | 0.016 | 0.149 | 0.138 | 0.001 | 0.280 | 0.887 | 0.399 |
| Group 9 | CT | | | 0.165 | 0.125 | 0.229 | 0.448 | 0.923 | 0.472 | 1.000 |
| | MT | | | 0.934 | 0.033 | 0.027 | 0.296 | 0.056 | 0.667 | 0.092 |
| | ZT | | | 0.494 | 0.219 | 0.765 | 0.021 | 0.325 | 0.377 | 0.815 |
| | | | | Mean % (SE) | | | | | | |
| Group 1 | CT | No [§] | 7 | 1.6 (0.3) | 50.5 (5.0) | 20.7 (3.6) | 3.7 (1.6) | 5.2 (3.0) | 9.3 (4.1) | 0.0 (0.0) |
| | CT | Yes | 9 | 2.1 (0.2) | 60.4 (5.7) | 19.2 (5.4) | 5.3 (1.9) | 4.5 (3.3) | 7.3 (3.9) | 0.0 (0.0) |
| | MT | No | 18 | 1.7 (0.1) | 49.1 (4.3) | 29.1 (4.0) | 5.8 (1.1) | 6.9 (2.3) | 12.5 (2.9) | 2.5 (1.7) |
| | MT | Yes | 63 | 1.6 (0.1) | 49.5 (2.4) | 18.2 (1.8) | 4.2 (0.8) | 2.7 (0.9) | 7.6 (1.3) | 2.0 (0.6) |
| | ZT | No | 8 | 1.8 (0.1) | 45.4 (6.6) | 27.1 (5.7) | 7.7 (2.2) | 0.7 (0.5) | 12.2 (5.1) | 4.6 (2.3) |
| | ZT | Yes | 13 | 1.5 (0.1) | 45.5 (5.0) | 25.3 (2.9) | 7.4 (1.9) | 3.3 (3.3) | 11.1 (2.2) | 0.6 (0.6) |
| Group 2 | CT | No | 11 | 1.9 (0.2) | 57.9 (4.5) | 17.7 (3.3) | 4.1 (1.2) | 3.3 (2.1) | 7.7 (2.8) | 0.0 (0.0) |
| | CT | Yes | 6 | 1.9 (0.1) | 51.9 (6.4) | 24.4 (7.9) | 5.7 (3.1) | 8.1 (5.2) | 9.3 (6.7) | 0.0 (0.0) |
| | MT | No | 42 | 1.7 (0.1) | 52.3 (2.9) | 19.1 (2.0) | 4.4 (0.7) | 3.1 (1.0) | 9.5 (1.8) | 1.6 (0.6) |
| | MT | Yes | 39 | 1.5 (0.1) | 46.3 (3.1) | 22.3 (2.9) | 4.7 (1.2) | 4.2 (1.5) | 7.8 (1.6) | 2.6 (1.0) |
| | ZT | No | 9 | 1.5 (0.1) | 42.2 (5.9) | 30.3 (4.7) | 5.8 (1.3) | 5.2 (4.6) | 15.5 (4.3) | 2.1 (1.5) |
| | ZT | Yes | 12 | 1.7 (0.1) | 47.8 (4.8) | 22.7 (2.7) | 8.8 (2.2) | 0.2 (0.2) | 8.5 (2.2) | 2.2 (1.4) |
| Group 4 | CT | No | 4 | 2.1 (0.2) | 60.3 (10.0) | 26.9 (9.1) | 9.0 (2.8) | 10.3 (8.4) | 3.8 (1.8) | 0.0 (0.0) |
| | CT | Yes | 13 | 1.8 (0.2) | 55.1 (4.1) | 18.2 (3.4) | 3.6 (1.3) | 3.5 (1.9) | 9.2 (3.1) | 0.0 (0.0) |
| | MT | No | 23 | 1.6 (0.1) | 50.1 (4.4) | 21.0 (3.8) | 3.7 (1.4) | 5.6 (1.9) | 7.5 (1.9) | 3.4 (1.7) |
| | MT | Yes | 58 | 1.6 (0.1) | 49.2 (2.4) | 20.5 (1.9) | 4.9 (0.8) | 2.8 (1.0) | 9.1 (1.5) | 1.6 (0.5) |
| | ZT | No | 5 | 1.4 (0.1) | 38.9 (9.1) | 31.2 (1.4) | 12.0 (3.7) | 0.0 (0.0) | 13.8 (3.3) | 1.5 (1.4) |
| | ZT | Yes | 16 | 1.7 (0.1) | 47.5 (4.1) | 24.3 (3.5) | 6.1 (1.3) | 3.1 (2.7) | 10.8 (2.9) | 2.3 (1.3) |
| Group 9 | CT | No | 9 | 2.0 (0.2) | 59.6 (6.1) | 16.2 (4.7) | 4.0 (1.9) | 4.5 (3.4) | 5.8 (3.1) | 0.0 (0.0) |
| | CT | Yes | 7 | 1.8 (0.2) | 51.5 (4.0) | 24.4 (4.5) | 5.4 (1.7) | 5.2 (2.9) | 11.2 (4.9) | 0.0 (0.0) |
| | MT | No | 26 | 1.7 (0.1) | 56.3 (3.0) | 15.5 (2.3) | 3.4 (0.9) | 1.5 (0.5) | 8.3 (2.1) | 0.9 (0.4) |
| | MT | Yes | 55 | 1.6 (0.1) | 46.2 (2.6) | 23.0 (2.3) | 5.1 (0.9) | 4.6 (1.3) | 8.8 (1.5) | 2.7 (0.8) |
| | ZT | No | 2 | 2.0 (0.1) | 61.0 (8.2) | 26.8 (8.0) | 4.1 (0.1) | 0.0 (0.0) | 18.5 (4.8) | 2.1 (1.6) |
| | ZT | Yes | 19 | 1.6 (0.1) | 43.8 (3.5) | 25.9 (2.8) | 7.9 (1.5) | 2.6 (2.3) | 10.8 (2.5) | 2.1 (1.1) |

[†]Cs, *Cochliobolus sativus*; Fus spp., total *Fusarium* spp.; Fav, *F. avenaceum*; Fc, *F. culmorum*; Fe, *F. equiseti*; Fg, *F. graminearum*.

[‡]CT, conventional-till; MT, minimum-till; ZT, zero-till.

[§]No, no herbicide of this group applied in previous 18 mo; Yes, herbicide of this group applied at least once in previous 18 mo.

ZT, which was present at higher levels in sprayed than unsprayed fields. In contrast, for Group 2 and 4 herbicides, there were generally lower levels of *Fusarium* spp. in sprayed than unsprayed fields under CT and/or ZT management.

Because of the high proportion of barley crops that were preceded by an oilseed crop and sprayed with Group 9 herbicides, and the positive effect of a previous oilseed crop on *Fusarium* spp., fields under MT that had had a crop

other than oilseed the previous year were analyzed separately. This analysis showed a similar association of previous Group 9 herbicide use with a lower level of *C. sativus* and a higher level of *Fusarium* spp. (data not presented).

Grain Yield

Barley grain yield was greater for six-rowed than for two-rowed barley (Table 6). Barley preceded by summer fallow, C–F, or C–C had significantly lower yields than after

a crop or other 2-yr sequences. Barley preceded by an oilseed crop or by two noncereal crops had the highest yields; these were also higher after O*-C than after C*-NC. There were no significant effects of tillage system on grain yield (data not presented).

Both herbicide Groups 1 and 9 were associated with higher grain yields, whereas Group 4 was associated with lower yields (Table 6). The increase in yield in sprayed versus unsprayed fields was 16% for Group 1 and 24% for Group 9, whereas the apparent yield decrease with Group 4 was 11%. For Group 1, the higher yield in sprayed fields may be related, at least partly, to the higher proportion of unsprayed barley fields preceded by summer fallow relative to those grown after a crop than for the other herbicide groups. When barley crops grown after a year of summer fallow were removed from the analysis, barley grown in fields sprayed with Group 1 herbicides had only a 9% higher mean yield (3279 kg ha⁻¹) than unsprayed fields (3010 kg ha⁻¹). For Group 9, because of the possible confounding effect of previous oilseed crops due to the preponderance of these crops (many of which were glyphosate-resistant canola) as the previous crop in sprayed fields, the association of herbicide use with yield was also analyzed separately for barley crops preceded by a crop other than an oilseed. This analysis showed that barley crops preceded by a cereal or pulse crop had a 20% higher mean yield when grown in fields that had received at least one Group 9 herbicide application (3171 kg ha⁻¹) compared with unsprayed fields (2634 kg ha⁻¹).

DISCUSSION

The greater susceptibility of two- than six-rowed barley cultivars to CRR agrees with what has been reported for registered barley cultivars in western Canada (Saskatchewan Agriculture, Food and Rural Revitalization, 2003).

Cochliobolus sativus was the most widespread and commonly isolated fungus from lesioned SIs of barley, followed by *Fusarium* spp. Among these, *F. avenaceum* and *F. equiseti* were the most prevalent and common isolates in the more severe SI lesions. The occurrence of *F. equiseti* in severely discolored tissue may be partly explained by its association with *C. sativus*; the former fungus, which is considered weakly to moderately pathogenic on cereals (Fedel-Moen and Harris, 1987; Gonzalez and Trevathan, 2000), likely acted as a secondary invader of tissue previously colonized by *C. sativus*. Similarly, the association of *M. bolleyi*, considered a weak pathogen of barley (Murray and Gadd, 1981), with the more severely discolored tissue could be, at least partly, attributed to the frequency with which this species occurred together with *C. sativus*.

Cropping sequence had less impact on the extent of SI discoloration (CRR) than tillage system, with only the relative levels of the most commonly isolated fungi being affected by the former crop production factor. In general,

Table 6. Effect of crop type, previous crop(s), and herbicide applications in the previous 18 mo, on grain yield of barley crops sampled in eastern Saskatchewan, 1999–2001.

| Effect, contrast | Number of crops | Grain yield |
|--|-----------------|-------------------------------|
| | | P value |
| Crop type (two- or six-rowed) | | 0.001 |
| | | Mean kg ha ⁻¹ (SE) |
| Two-rowed | 50 | 2791 (117) |
| Six-rowed | 87 | 3399 (82) |
| | | P value |
| Previous crop | | 0.001 |
| Cereal vs. oilseed | | 0.000 |
| Oilseed vs. cereal or pulse | | 0.019 |
| Summer fallow vs. others | | 0.090 |
| | | Mean kg ha ⁻¹ (SE) |
| Cereal | 50 | 2934 (111) |
| Oilseed | 59 | 3503 (102) |
| Pulse | 11 | 3095 (252) |
| Summer fallow | 14 | 2714 (169) |
| | | P value |
| Previous two crops ¹ | | 0.039 |
| C-C vs. C-NC, NC-NC | | 0.013 |
| C-C vs. C-F | | 0.569 |
| | | Mean kg ha ⁻¹ (SE) |
| C-C | 15 | 2745 (210) |
| C-NC | 74 | 3249 (86) |
| NC-NC | 11 | 3728 (327) |
| C-F | 16 | 2691 (217) |
| NC-F | 18 | 3271 (169) |
| | | P value |
| Previous two crops, by first crop ² | | 0.003 |
| C*-NC vs. O*-C | | 0.012 |
| | | Mean kg ha ⁻¹ (SE) |
| C*-NC | 32 | 3050 (122) |
| O*-C | 36 | 3473 (114) |
| | | P value |
| Herbicide use | | |
| Group 1 | | 0.049 |
| Group 2 | | 0.191 |
| Group 4 | | 0.078 |
| Group 9 | | 0.001 |
| | | Mean kg ha ⁻¹ (SE) |
| Group 1: No ³ | 18 | 2801 (234) |
| Group 1: Yes | 62 | 3239 (86) |
| Group 2: No | 41 | 3023 (129) |
| Group 2: Yes | 39 | 3274 (112) |
| Group 4: No | 22 | 3382 (158) |
| Group 4: Yes | 58 | 3050 (99) |
| Group 9: No | 25 | 2698 (133) |
| Group 9: Yes | 55 | 3345 (101) |

¹C, cereal; NC, noncereal; F, summer fallow. Barley crops grouped according to previous two crops, regardless of the order in the sequence (C-C, C-NC, NC-NC, C-F, and NC-F).

²Barley crops grouped according to first crop in the previous 2-yr crop sequence (e.g., C*-NC for cereal as the first crop, O*-C for oilseed [O] as the first crop in the C-NC sequence).

³No, no herbicide of this group applied in previous 18 mo; Yes, herbicide of this group applied at least once in previous 18 mo.

tillage effects on SI discoloration or percentage fungal isolations did not seem to depend on the previously grown crop. While CRR and *C. sativus* isolations from SI were favored by CT management, colonization by *Fusarium* spp., especially *F. avenaceum* and *F. graminearum*, increased under reduced tillage. Our observations on tillage effects on the relative prevalence of these fungi agree with previous studies. In particular, the higher levels of *C. sativus* and lower levels of *F. avenaceum* in more intensive tillage systems are similar to observations by Windels and Wiersma (1992), who reported an increase in *F. avenaceum* and *F. graminearum* in barley with a reduction in tillage intensity, but no tillage effect for *F. acuminatum* or *F. culmorum*. In other studies conducted in eastern Saskatchewan, tillage operations were also positively associated with the occurrence of *C. sativus* and negatively associated with that of *F. avenaceum* in SIs of common wheat (Fernandez et al., 2007a) and roots of lentil (*Lens culinaris* Medik.), and flax and canola plants grown in rotation with wheat or barley (Fernandez, 2007).

Cochliobolus sativus also occurred at higher levels in barley grown in production systems of cereals alternated with summer fallow under CT or MT management than in most other sequences. However, levels of this fungus in barley grown immediately after summer fallow were not significantly different than when grown after a crop. Piening et al. (1969) found higher levels of CRR in barley caused mostly by *C. sativus* when grown after summer fallow than stubble, whereas Piening and Orr (1988) found that CRR in barley was lower after summer fallow than after another susceptible crop. For the most part, *Fusarium* spp. were also not significantly affected by summer fallow versus a crop, except for *F. culmorum*, which was significantly reduced when barley was grown after summer fallow or after a cereal crop and summer fallow. This contrasts with observations by Fernandez et al. (2007a) and Sturz and Johnston (1985), who found lower levels of *F. avenaceum* in wheat SIs and crowns, respectively, when grown after summer fallow than stubble.

Although an oilseed crop grown in the previous year was associated with lower levels of *C. sativus* in barley than a cereal crop, barley grown after 2 yr of noncereal crops had lower levels of this pathogen than when grown after a cereal alternated with a noncereal crop, although its levels were not significantly different than after two cereal crops. These observations only partly agree with those of Conner et al. (1996) and Piening and Orr (1988), who found higher CRR levels in barley when grown on barley stubble than when grown following 2 yr of noncereal crops.

Growing a noncereal crop in the previous 1 or 2 yr was in turn associated with higher levels of *Fusarium* spp. in the succeeding barley crop compared with a cereal crop or other continuous sequences that included a cereal crop. This could be attributed to higher levels of *F. avenaceum*, *F.*

culmorum, *F. equiseti*, and *F. graminearum* observed after an oilseed and/or pulse crop, or after 2 yr of noncereal crops. Fernandez et al. (2007a) reported higher levels of *F. avenaceum* in SIs of common wheat grown after a pulse than a cereal crop, or after a 2-yr sequence that included at least one noncereal crop than after two cereal crops. Most of the barley crops grown after a noncereal crop, or after two noncereal crops, were under reduced tillage (MT or ZT), which may have confounded these results, considering the positive effect of reduced tillage on *Fusarium* isolations. However, barley grown after NC-F (mostly under CT or MT) had similar levels of *Fusarium* spp. than when grown after NC-NC, suggesting that the previously grown crop had a greater impact on these fungi than the method of tillage management.

The positive relationship of reduced tillage systems and previously grown noncereal crops with *Fusarium* spp. in SIs and the association of *F. graminearum* with a previously grown oilseed crop were similar to that observed for spike infections of the same barley crops (Fernandez et al., 2007b). The mechanism(s) by which noncereal crops, most of which were canola, contributed to the higher populations of *F. avenaceum* and *F. graminearum*, especially the latter, in SIs of barley is not known. However, in both of these barley studies and a spring wheat study conducted in the same area and during the same years (Fernandez et al., 2005), there was also a positive impact of glyphosate applied mostly on fields where canola had been grown on pathogenic *Fusarium* spp., including *F. avenaceum*, *F. culmorum*, and *F. graminearum*. Glyphosate was in fact the only herbicide associated with higher levels of *Fusarium* spp. in SIs of barley in the present study. Although analysis of barley crops grown after a crop other than canola showed similar associations of *Fusarium* isolations with previous glyphosate applications, because of the nature of these studies, the impact of a previously grown canola crop from that of previous glyphosate applications could not be completely separated.

In addition to a positive association of previous glyphosate use with isolation of *Fusarium* spp. from barley SIs, this study also showed a significant negative association of previous glyphosate use with *C. sativus*, suggesting changes in populations of the most common root rot fungi associated with the use of this herbicide. No other herbicide group seemed to consistently affect levels of this cereal pathogen. The observation that similar negative associations of previous glyphosate use with *C. sativus* were also apparent under CT- and ZT-management systems suggests that changes in levels of this pathogen may be due to direct effect(s) of this herbicide and are not related to tillage management. There are no previous reports of glyphosate effects on infection of barley underground tissue by *C. sativus*; however, Fernandez et al. (2007a) also found a negative association of previous glyphosate application with levels of *C. sativus* in SIs of common wheat sampled in the same

area. The observation that *Fusarium* spp. increased in fields previously treated with glyphosate formulations agrees with previous reports on *Fusarium* colonization of other crops being associated with glyphosate use. For example, Levesque et al. (1987) reported that glyphosate application increased root colonization of various treated weeds by *F. avenaceum* and *F. oxysporum* Schlechtend.:Fr., and it also increased the propagule density of these *Fusarium* spp. in the soil. In addition, Levesque et al. (1993) reported that glyphosate-treated wheat seedlings were colonized to a greater extent than untreated seedlings by *Fusarium* spp. under warm and dry conditions than under lower temperatures and moist conditions. Further, glyphosate-treated quack grass [*Elymus repens* (L.) Gould] rapidly colonized by *F. culmorum* caused damage to a subsequent barley crop (Lynch and Penn, 1980).

From our data, we could not determine if the higher *Fusarium* levels associated with previous glyphosate use was due to effects on fungal inoculum or host susceptibility or to the absence of competition from *C. sativus*. Furthermore, how much the observed association with previous glyphosate use contributed to increased relative levels of *Fusarium* spp. in reduced tillage systems, and how much might be due to other factors such as microenvironment in these systems, could also not be determined. Separating the effects of the various agronomic practices relating to cropping sequence and tillage system would be necessary to understand the role that each of these play in disease levels and the relative frequency of the various pathogens.

In general, six-rowed barley crops yielded more than two-rowed barley crops. Grain yield also appeared to be more affected by previous crop(s) or summer fallow than by tillage system. However, the effects of these agronomic factors could not be completely separated. The higher yields of barley grown after two consecutive crops that included at least one noncereal crop than when grown after two cereal crops, or a cereal alternated with summer fallow, should be attributed, at least partly, to higher N input, and/or the higher soil N available that would be expected in diversified cropping sequences. Piening et al. (1983) showed that the yield of barley increased, and CRR decreased, in barley grown on stubble when fertilizer (N and P) was added. In our study, as indicated above, although barley grown after some of the continuous diversified sequences had lower levels of *C. sativus* than when grown after C-F, sequences consisting only of noncereal crops had higher levels of *Fusarium* spp., resulting in similar overall CRR levels among cropping sequences. In addition, the coincidence of higher grain yields with a previous oilseed crop was also confounded by an association of yield with glyphosate use in fields under MT management given that most of the fields that received glyphosate applications in the previous 18 mo had been planted to an oilseed crop the year previous. However, analysis of barley crops preceded by a crop other than an

oilseed showed that glyphosate applications in the previous 18 mo also had a similar positive effect on yield as for all crops combined. The greater yield advantage of barley crops grown in fields previously sprayed with glyphosate is likely a reflection of the greater weed control provided by this nonselective herbicide.

Based on the results of this CRR survey of barley crops conducted in eastern Saskatchewan, we conclude that growing barley under reduced tillage systems that include glyphosate applications and with noncereal crops incorporated in the rotation will result in lower levels of *C. sativus*, the most common CRR pathogen in western Canada. However, these production systems will likely result in an increase in infection by *Fusarium* spp. Although the latter remained at lower levels than *C. sativus*, increases in populations of *F. avenaceum* and *F. graminearum*, especially in areas with higher disease pressure than where the present study was conducted, may cause greater development not only of crown and root rot but also of spike infections in subsequently grown cereal crops. Because *Fusarium* infections in crowns and roots are less affected by environmental conditions than spike infections, they may also contribute to the maintenance of inoculum in years not conducive to FHB development and thus to the further spread of this disease in the Canadian Prairies. As suggested by Fernandez et al. (2007b) for a study of FHB and *Fusarium*-damaged kernels on the same barley crops sampled in this study, the observation that similar crop production factors were associated with some of the most common pathogenic *Fusarium* spp. in SLs and spikes and kernels of barley suggests that measures aimed at reducing crown and root rot caused by *Fusarium* spp. may also help reduce FHB development in this cereal crop on the Canadian Prairies.

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References

- Burgess, L.W., C.M. Liddell, and B.A. Summerell. 1988. Laboratory manual for *Fusarium* research. 2nd ed. Univ. of Sidney, Sidney, Australia.
- Conner, R.L., L.J. Ducek, G.C. Kozub, and A.D. Kuzyk. 1996. Influence of crop rotation on common root rot of wheat and barley. Can. J. Plant Pathol. 18:247-254.
- Fedel-Moen, R., and J.R. Harris. 1987. Stratified distribution of *Fusarium* and *Bipolaris* on wheat and barley with dryland root rot in South Australia. Plant Pathol. 36:447-454.
- Fernandez, M.R. 2007. *Fusarium* populations in roots of oilseed and pulse crops grown in eastern Saskatchewan. Can. J. Plant Sci. (in press).
- Fernandez, M.R., P. Basnyat, and R.P. Zentner. 2007a. Response of wheat root pathogens to crop management in eastern Saskatchewan. Can. J. Plant Sci. (in press).

- Fernandez, M.R., and Y. Chen. 2005. Pathogenicity of *Fusarium* species on different plant parts of spring wheat under controlled conditions. *Plant Dis.* 89:164–169.
- Fernandez, M.R., and P.G. Jefferson. 2004. Fungal populations in roots and crowns of common and durum wheat in Saskatchewan. *Can. J. Plant Pathol.* 26:325–334.
- Fernandez, M.R., F. Selles, D. Gehl, R.M. DePauw, and R.P. Zentner. 2005. Crop production factors associated with *Fusarium* head blight in spring wheat in eastern Saskatchewan. *Crop Sci.* 45:1908–1916.
- Fernandez, M.R., R.P. Zentner, R.M. DePauw, D. Gehl, and F.C. Stevenson. 2007b. Impacts of crop production factors on *Fusarium* head blight in barley in eastern Saskatchewan, Canada. *Crop Sci.* 47:1574–1584.
- Gonzalez, M.S., and L.E. Trevathan. 2000. Identity and pathogenicity of fungi associated with root and crown rot of soft red winter wheat grown on the Upper Coastal Plain Land Resource Area of Mississippi. *J. Phytopathol.* 148:77–85.
- Ledingham, R.J., T.G. Atkinson, J.S. Horricks, J.T. Mills, L.J. Piening, and R.D. Tinline. 1973. Wheat losses due to common root rot in the Prairie provinces of Canada, 1969–71. *Can. Plant Dis. Surv.* 53:113–122.
- Levesque, C.A., J.E. Rahe, and D.M. Eaves. 1987. Effects of glyphosate on *Fusarium* spp.: Its influence on root colonization of weeds, propagule density in the soil, and crop emergence. *Can. J. Microbiol.* 33:354–360.
- Levesque, C.A., J.E. Rahe, and D.M. Eaves. 1993. Fungal colonization of glyphosate-treated seedlings using a new root plating technique. *Mycol. Res.* 97:299–306.
- Lynch, J.M., and D.J. Penn. 1980. Damage to cereals caused by decaying weed residues. *J. Sci. Food Agric.* 31:321–324.
- Murray, D.I.L., and G.M. Gadd. 1981. Preliminary studies on *Microdochium bolleyi* with special reference to colonization of barley. *Trans. Br. Mycol. Soc.* 76:397–403.
- Pearse, P.G., G. Holzgang, C.L. Harris, and M.R. Fernandez. 2006. *Fusarium* head blight in barley and oat in Saskatchewan in 2005. *Can. Plant Dis. Surv.* 86:45–46.
- Piening, L.J., T.G. Atkinson, J.S. Horricks, R.J. Ledingham, J.T. Mills, and R.D. Tinline. 1976. Barley losses due to common root rot in the Prairie provinces of Canada, 1970–72. *Can. Plant Dis. Surv.* 56:41–45.
- Piening, L., R. Edwards, and D. Walker. 1969. Effect of some cultural practices on root rot of barley in central Alberta. *Can. Plant Dis. Surv.* 49:95–97.
- Piening, L.J., and D. Orr. 1988. Effects of crop rotation on common root rot of barley. *Can. J. Plant Pathol.* 10:61–65.
- Piening, L.J., D.R. Walker, and M. Dagenais. 1983. Effect of fertilizer on root rot of barley on stubble and fallow land. *Can. J. Plant Pathol.* 5:136–139.
- Pua, E.C., R.L. Pelletier, and H.R. Klinck. 1985. Seedling blight, spot blotch, and common root rot in Quebec and their effect on grain yield in barley. *Can. J. Plant Pathol.* 7:395–401.
- Samson, R.A., E.S. Hoekstra, J.C. Frisvad, and O. Filtenborg. 2002. Introduction to food- and air-borne fungi. 6th ed. Centraalbureau voor Schimmelcultures, Utrecht, the Netherlands.
- SAS Institute. 1999. SAS OnlineDoc, version 8. SAS Inst., Cary, NC.
- Saskatchewan Agriculture and Food. 2006. 2006 guide to crop protection. Saskatchewan Agriculture and Food, SK.
- Saskatchewan Agriculture, Food and Rural Revitalization. 2003. Saskatchewan varieties of grain crops 2003. Saskatchewan Agriculture, Food and Rural Revitalization, Regina, SK.
- Sturz, A.V., and M.R. Carter. 1995. Conservation tillage systems, fungal complexes and disease development in soybean and barley rhizosphere in Prince Edward Island. *Soil Tillage Res.* 34:225–238.
- Sturz, A.V., and H.W. Johnston. 1985. Characterization of *Fusarium* colonization of spring barley and wheat produced on stubble or fallow soil. *Can. J. Plant Pathol.* 7:270–276.
- Tekauz, A., J. Gilbert, E. Mueller, M. Stulzer, and M. Beyene. 2006. Survey for *Fusarium* head blight of barley in Manitoba in 2005. *Can. Plant Dis. Surv.* 86:37–38.
- Tekauz, A., B. McCallum, and J. Gilbert. 2000. Review: *Fusarium* head blight of barley in western Canada. *Can. J. Plant Pathol.* 22:9–16.
- Tinline, R.D., and R.J. Ledingham. 1979. Yield losses in wheat and barley cultivars from common root rot in field tests. *Can. J. Plant Sci.* 59:313–320.
- Watanabe, T. 2002. Pictorial atlas of soil and seed fungi. Morphologies of cultured fungi and key to species. 2nd ed. CRC Press, Boca Raton, FL.
- Windels, C.E., and J.V. Wiersma. 1992. Incidence of *Bipolaris* and *Fusarium* on subcrown internodes of spring barley and wheat grown in continuous conservation tillage. *Phytopathology* 82:699–705.
- Zadoks, J.C., T.T. Chang, and C.F. Konzak. 1974. A decimal code for the growth stages of cereals. *Weed Res.* 14:415–421.

RESEARCH

Impacts of Crop Production Factors on Fusarium Head Blight in Barley in Eastern Saskatchewan

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ABSTRACT

Fusarium head blight (FHB) in barley (*Hordeum vulgare* L.) is well established in the eastern Canadian Prairies and appears to be moving westward. A survey of 192 barley crops in eastern Saskatchewan was conducted to determine the impact of agronomic practices on FHB (1999–2002) and *Fusarium*-damaged kernels (FDK) (2000–2001). The most common species isolated from spikes and kernels were *F. sporotrichioides*, *F. avenaceum*, and *F. graminearum*, followed by *F. poae* and *F. culmorum*. Disease tended to be higher under minimum-till compared with conventional- or zero-till. *Fusarium sporotrichioides* was favored by a previous cereal crop, whereas *F. avenaceum* was higher after a pulse crop, and *F. graminearum* decreased after a pulse but not an oilseed crop. The latter two pathogens were also more prevalent after diversified cropping sequences than after two cereal crops. Summer fallow, or summer fallow alternated with cereals, decreased FDK. Previous glyphosate (Group 9 herbicides) use was associated with increased infection by all *Fusarium* spp., whereas Group 1 herbicides were associated with increased infection by *F. poae* and *F. sporotrichioides*. Effects of both herbicide groups depended on tillage system. Number of previous glyphosate applications was also correlated with FHB caused by *F. avenaceum* and *F. graminearum*. We concluded that in eastern Saskatchewan, barley grown under minimum-till where glyphosate had been sprayed and following diversified cropping sequences would sustain the greatest damage due to FHB and FDK caused by *F. avenaceum* and *F. graminearum*.

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Abbreviations: C, cereal; CT, conventional-till; DON, deoxynivalenol; F, summer fallow; Fav, *Fusarium avenaceum*; FDK, *Fusarium*-damaged kernels; Fg, *Fusarium graminearum*; FHB, Fusarium head blight; Fp, *Fusarium poae*; Fspo, *Fusarium sporotrichioides*; MT, minimum-till; NC, noncereal; ZT, zero-till.

FUSARIUM HEAD BLIGHT (FHB), also known as scab or tombstone, became an important barley (*Hordeum vulgare* L.) disease in the eastern Canadian Prairies about 1997 (Tekauz et al., 2000) and has since spread westward, with negative impacts on grain yield and quality in years conducive to disease development. Fusarium head blight surveys conducted throughout the Canadian Prairies detected head and kernel infections of barley crops in eastern Saskatchewan (Clear et al., 2000; Fernandez et al., 2002) and Alberta (Turkington et al., 2002), although in fewer fields and at lower levels than in Manitoba (Tekauz et al., 2000). In the last few years, due to unfavorable weather for disease development at flowering, FHB has occurred at low levels in Saskatchewan (Pearse et al., 2006); however, there is still the potential for this disease to continue spreading westward and adversely impact the production and marketing opportunities for barley in these regions.

Barley is second only to spring wheat (*Triticum aestivum* L.) in terms of the land area devoted to cereal production on the

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Canadian Prairies. Of the 4.1 million ha of barley grown annually, mainly in the subhumid Parkland region (Campbell et al., 2002), about 75% is planted to cultivars developed for the malting industry and 25% is planted to feed cultivars for use in animal rations. Both two-rowed and six-rowed malt barley cultivars are grown in an approximate ratio of two to one.

Several *Fusarium* species can cause FHB in barley. The most important FHB pathogen in Manitoba and in the midwestern USA is *F. graminearum* Schwabe [teleomorph *Gibberella zeae* (Schwein.) Petch], followed by other species, the most common of which are *F. avenaceum* (Fr.:Fr.) Sacc. (teleomorph *G. avenacea* Cook), *F. poae* (Peck) Wollenweb., and *F. sporotrichioides* Sherb. (Salas et al., 1999; Tekauz et al., 2000, 2006). Sturz and Johnston (1985) reported that the most common species isolated from barley spikes in Prince Edward Island in the early 1980s were *F. graminearum* and *F. poae*, followed mainly by *F. avenaceum* and *F. culmorum* (W.G. Smith) Sacc. In Saskatchewan and Alberta, *F. graminearum* has been less commonly isolated from infected barley spikes and kernels than in regions where the disease is more prevalent. *Fusarium avenaceum* was reported as the most or one of the most common species found in infected spikes and kernels of barley (Clear et al., 2000; Pearse et al., 2006; Turkington et al., 2002).

Because *F. graminearum* is the most important FHB pathogen in the most affected barley-producing areas, deoxynivalenol (DON) has been reported as the most important mycotoxin in infected crops. Nonetheless, other mycotoxins have also been associated with infection of barley by other *Fusarium* spp. (Abramson et al., 2002; Campbell et al., 2000; Salas et al., 1999).

The best resistance in cultivars registered in western Canada was described as "Fair" or "Fair+" by Saskatchewan Agriculture, Food and Rural Revitalization (2005). For malting barley (Special Select), the tolerance for *Fusarium*-damaged kernels (FDK) is Nil, and for Select and Standard Select, it is 0.2% (Canadian Grain Commission, 2005).

Reducing FHB levels and preventing continued damage to the barley industry will help Canadian producers remain competitive and protect market opportunities. Although the most effective way of controlling FHB is by developing barley cultivars with improved levels of resistance, knowing which agronomic practices contribute to reduced disease and inoculum levels should form part of a comprehensive strategy for disease control. There are few reported studies on the impact of agronomic practices on FHB in barley. In studies conducted in Quebec, Rioux et al. (2005) found that DON content was greater in barley grown under minimum-till rather than conventional-till management and that barley preceded by a mixed forage crop of orchardgrass (*Dactylis glomerata* L.) and red clover (*Trifolium pratense* L.) had a higher DON content than barley grown in monoculture. There are no consistent crop rotation or tillage system effects on disease development

among studies conducted on wheat (Dill-Macky and Jones, 2000; Fernandez et al., 2005; Miller et al., 1998; Schaafsma et al., 2001). In all the latter studies, *F. graminearum* was the predominant pathogen in spikes or kernels.

The objective of this study was to determine how FHB and FDK development, and relative prevalence of *Fusarium* pathogens, in barley crops grown in eastern Saskatchewan is affected by crop production systems, in particular, tillage method and cropping sequence. This information would help to identify agronomic practices that may reduce the further spread of damage to barley from FHB on the Canadian Prairies.

MATERIALS AND METHODS

Description of Fields Sampled

Commercial fields (experimental units) were selected at random within Crop Districts 1B and 5A in southeast and east-central Saskatchewan to represent the most common cropping practices in the area. The bulk of the agricultural soils of these regions are Black Chernozems, derived from glacial deposits with loam to clay loam texture (Padbury et al., 2002). The depth of the surface horizon averages 20 to 25 cm, and the soils contain about 7% organic matter. Further details about the study area were reported by Fernandez et al. (2005).

A total of 192 barley crops were sampled from 1999 to 2002 (30 in 1999, 63 in 2000, 50 in 2001, and 49 in 2002). The most common barley cultivars sampled were Excel (19% of all crops sampled in all 4 yr), Metcalfe and Robust (14% each), Harrington (8%), CDC Stratus (7%), and CDC Dolly (6%). The remaining barley cultivars constituted less than 5% each of all the crops sampled. The average seeding dates for the barley crops sampled were 3 June 1999, 16 May 2000, 21 May 2001, and 20 May 2002. The average harvest dates were 23 Sept. 1999, 10 Sept. 2000, 2 Sept. 2001, and 13 Sept. 2002.

Spike and Grain Sampling

At the mid-milk to early-dough stage of crop development (growth stages 75–83; Zadoks et al., 1974), 100 spikes from each field were taken at random, following a large circular pattern. Sampling started about 40 m from the edge of the field. Samples were placed in paper bags, transported to the Semiarid Prairie Agricultural Research Centre near Swift Current, Saskatchewan, dried at 40°C for 48 h, and stored in a cold (4°C) room until analysis in late summer/early fall. An estimate of percentage of spikes with FHB-like symptoms (incidence) was based on 50 spikes taken randomly from the 100 collected spikes. Disease severity was estimated visually based on the percentage of spikelets discolored on each spike. To confirm infection by *Fusarium* spp. and for species identification, the individual lemma showing discoloration were carefully removed, surface-sterilized for 1 min in 0.6% NaOCl, and rinsed twice in sterile distilled water. They were then plated on modified potato dextrose agar (Burgess et al., 1988; Fernandez and Chen, 2005) and incubated for 7 d under fluorescent and near-UV lights at 22°C day/15°C night, 16 h photoperiod (light intensity of 110 $\mu\text{mol s}^{-1} \text{m}^{-2}$). *Fusarium* spp. were identified on the basis of colony and spore morphology and reproductive structures using descriptions and keys in

Samson et al. (2002) and Watanabe (2002). A FHB index [(% of spikes infected \times mean severity of infection)/100] was calculated for each of the barley crops sampled based on the presence of *Fusarium* isolates in the discolored lemma tissue plated. From 2000 to 2002, FHB indices were also calculated for each crop based on the percentage isolation of the most common *Fusarium* spp.: *F. avenaceum* (FHB-Fav), *F. graminearum* (FHB-Fg), *F. poae* (FHB-Fp), and *F. sporotrichioides* (FHB-Fspo).

In 2001 and 2002, grain samples from most of the barley crops sampled were also obtained from cooperating producers. Kernels with FDK-like symptoms were visually identified in a 50-g subsample, removed, and weighed. The percentage of FDK-like symptoms was determined based on total weight of the sample. A subsample of up to 30 to 40 kernels with FDK symptoms was then plated on modified potato dextrose agar as above, and fungi growing out of kernels were identified after 7 to 10 d of incubation. A percentage "total FDK" was then calculated based on the percentage isolation of *Fusarium* spp. In addition, percentage FDKs was also calculated based on the percentage isolation of the most common species (FDK-Fav, FDK-Fg, FDK-Fp, and FDK-Fspo).

Categorization of Barley Crops/Fields into Crop Production Factors

At the end of the growing season, each producer provided information regarding the agronomic practices used on the crop(s) sampled. The information included cultivar, crop history, method of tillage management, pesticide use, and fertilizer rates. The information obtained from producers was used to categorize the crops/fields according to crop production factor, which was then used for further analysis to determine the association of each production factor with the various disease parameters.

For cultivar susceptibility to FHB, barley crops were categorized into "susceptible" and "intermediate" cultivars. Susceptible cultivars were those rated as "Poor," and intermediate cultivars were those rated as "Fair" or "Fair+" by Saskatchewan Agriculture, Food and Rural Revitalization (2005).

For tillage system, fields were categorized according to the total number of tillage operations they received in the previous 3 yr. Fields under "conventional-till" (CT) had a total of seven or more tillage operations, and those under "minimum-till" (MT) had a total of one to six operations (i.e., up to two tillage passes per year). There were no tillage operations in fields under "zero-till" (ZT) management during the same time period. The number of tillage operations in the previous 3 yr for fields under MT averaged 3.2, whereas for fields under CT the average was 8.5. Residue cover was not estimated for any field. Overall, more crops were grown under MT (61%) than under CT (18%) or ZT (22%). Herbicide applications within each tillage system were categorized according to whether the fields had received any of the herbicide Groups 1, 2, 4, and 9 (Saskatchewan Agriculture and Food, 2006) in the previous 18 months.

For previously grown crop(s), fields were categorized according to the crop, if any, grown the previous year: cereal, oilseed, pulse, or summer fallow. The most common crop planted the year before the barley crop sampled was an oilseed (44% of all crops sampled in all 4 yr), with canola (*Brassica* spp.) constituting 76% of all oilseed crops. The second most common

crop planted before barley was a cereal (39%), whereas the least common was a pulse (7%). Summer fallow was practiced on an average of 10% of fields the year before barley. Fields were also categorized according to the crops, if any, grown the previous 2 yr, regardless of the order in the sequence: two cereal (C) crops (C-C), two noncereal (NC) crops (NC-NC), a combination of a cereal and a noncereal crop (C-NC), or summer fallow (F) and a crop (C-F or NC-F). Most barley crops grown after a cereal or oilseed crop were under MT (60–63%), followed by ZT (20–26%); most grown after a pulse crop were under either MT or ZT (76%); and most of those grown after summer fallow were under CT (35%) or MT (65%). When fields were categorized according to the two previous crops, most barley crops grown after C-C or C-NC (74–92%) or NC-NC (100%) were under MT or ZT, whereas most crops grown after C-F or NC-F were under MT (60–65%), followed by CT (30–40%).

Based on fertilizer input in the spring and/or previous fall, barley crops on average preceded by a cereal or oilseed crop had received the most N (mean of 62–63 kg ha⁻¹), followed by those grown after a pulse crop (51 kg ha⁻¹), with crops grown after summer fallow having received the least N (27 kg ha⁻¹). Based on the categorization of fields according to the previous two crops, barley grown after C-NC received the most N (mean of 65 kg ha⁻¹), followed by C-C, NC-NC, and NC-F (53–55 kg ha⁻¹), with crops grown after C-F receiving the least N (34 kg ha⁻¹). No soil N testing was performed on any of the fields sampled.

Weather data for May to August for three locations in each of the crop districts from 1999 to 2001 were obtained from Environment Canada (2003) and reported by Fernandez et al. (2005). Spring 1999 was cooler and wetter than the following 3 yr, especially 2000 and 2001, and the long-term mean. The month of July, when most barley crops would have flowered, had the highest mean maximum temperature and lowest precipitation in 2002, and highest precipitation in 2001 (mean maximum temperature for 1999: 23.8°C; 2000: 25.8°C, 2001: 25.0°C; and 2002: 26.7°C; precipitation for 1999: 75 mm, 2000: 84 mm; 2001: 60 mm; and 2002: 55 mm).

Statistical Analyses

Disease- and fungal-related responses were compared with SAS's SURVEYREG procedure, and means were estimated with the SURVEYMEANS procedure (SAS Institute, 1999). The analysis included the barley crop susceptibility classification cross classified with cropping sequence or tillage system. Data collected for each year were assumed to be stratum for the analysis. The rate at which each stratum was sampled was based on the actual number of samples divided by the total number of barley producers in Saskatchewan (assumed to be one-half of 11130 for barley; derived from <http://www.statcan.ca/english/Pgdb/agrc22i.htm>; verified 14 June 2007). Effects were declared significant at $P \leq 0.10$. Contrasts were performed among cropping sequences and tillage systems for total FHB index or percentage FDK, and for those attributed to the most commonly isolated fungi. Only the contrasts that showed significant effects for at least one of these parameters are presented in the tables. Fungi for which there were no significant effects of previous crop/cropping sequence or tillage system were not included in the tables. Pearson correlations were also performed between the FHB indices and percentage FDK attributed to the various fungi.

The effect of herbicide application was further examined for disease-related variables for each of the tillage systems. Differences among the different herbicide group treatments (applied: yes/no) for the 18-mo data were analyzed separately with SAS's SURVEYREG procedure, and means were estimated with the SURVEYMEANS procedure (SAS Institute, 1999). Pearson correlations were performed between the total number of Group 9 herbicide applications in the previous 18 mo and the FHB indices. Effects were again declared significant at $P \leq 0.10$.

RESULTS

FHB, FDK, and *Fusarium* Species in Infected Spikes and Kernels

Percentage of barley fields affected and mean FHB levels were higher in 2000 and 2001 than in 1999 or 2002 (Table 1). Percentage FDK in 2000 and 2001 was high enough to cause downgrading of the grain from Special Select to Select/Standard Select or feed (Canadian Grain Commission, 2006).

Most common fungal species isolated from FHB-affected barley spikes in 2000 and 2001 were *F. sporotrichioides*, followed by *F. avenaceum* and *F. graminearum* (Table 1). *Fusarium culmorum* and *F. poae* accounted for a lower percentage of the FHB index; however, in 2002 *F. poae*

accounted for most of the FHB damage in the barley crops sampled, and in 1999, it was the most frequently isolated species from discolored spikes. The species responsible for most of the FDK in 2000 and 2001 were *F. sporotrichioides*, *F. avenaceum*, and *F. graminearum*. Among other species isolated occasionally from spikes or kernels were *F. acuminatum* Ellis & Everh., *F. equiseti* (Corda) Sacc., and *F. oxysporum* Schlecht.:Fr.

The relative prevalence of *Fusarium* spp. on kernels after harvest was similar to that observed on spikes during kernel development. Simple correlations performed between FHB and FDK attributed to the most common fungi showed significant ($P \leq 0.01$ – 0.05) moderate correlations for *F. avenaceum* ($r = 0.26$ and 0.31 , for 2000 and 2001, respectively), *F. graminearum* ($r = 0.59$ and 0.64), and *F. sporotrichioides* ($r = 0.34$ and 0.42).

FHB and Crop Production Factors

When FHB data were analyzed based on cropping sequence, total FHB index, and that attributed to *F. avenaceum* and *F. graminearum* were significantly higher for susceptible cultivars than for those with intermediate resistance (Table 2). However, there were no significant effects of cropping sequence on the total FHB index but only on the FHB indices attributed to *F. avenaceum* and

F. graminearum. For the most part, there were no interactions of cropping sequence with cultivar susceptibility. Barley tended to have higher mean levels of FHB-*Fav* when grown after a pulse crop, although this varied, with cultivar susceptibility being the highest for susceptible cultivars (1.0%) (data by cultivar susceptibility not presented). Levels of FHB-*Fav* were also lower after C–C than after the other cropping sequences with two consecutive crops. In contrast, FHB-*Fg* was present at the lowest mean levels in barley grown after a pulse crop but tended to be higher after an oilseed than a cereal crop. Similar to FHB-*Fav*, FHB-*Fg* was also lower after C–C than after continuous cropping sequences with at least one noncereal crop in the previous 2 yr. Instead, FHB-*Fp* was lower after NC–NC than after sequences that included cereal crops (C–C or C–NC) ($P = 0.043$ – 0.058). Barley grown after a cereal had a higher FHB-*Fspo* than when grown after an oilseed crop, and although nonsignificant for all crops combined, levels of FHB-*Fspo* were among the highest after C–C and the lowest after NC–NC for both susceptible and intermediate cultivars (data by cultivar susceptibility not presented).

Table 1. Percentage of barley crops with *Fusarium* head blight (FHB) and *Fusarium*-damaged kernels (FDK), mean and range for FHB index and percent FDK, and mean FHB index and percentage FDK attributed to *F. avenaceum*, *F. culmorum*, *F. graminearum*, *F. poae*, and *F. sporotrichioides*, in Crop Districts 1B and 5A in eastern Saskatchewan, 1999–2002.

| | Percentage occurrence | | | | Mean | | | |
|--|-----------------------|------|------|------|----------------|--------|----------|-------|
| | 1999 | 2000 | 2001 | 2002 | 1999 | 2000 | 2001 | 2002 |
| | % | | | | | | | |
| FHB (1999–2002) | | | | | | | | |
| Percentage occurrence/ FHB index | 80 | 95 | 94 | 59 | 0.5 | 2.7 | 2.1 | 0.2 |
| FHB index range | – | – | – | – | 0–0.6 | 0–21.9 | 0–6.7 | 0–2.0 |
| FHB index attributed to | | | | | | | | |
| <i>F. avenaceum</i> | 27 | 56 | 70 | <1 | – ¹ | 0.4 | 0.5 | <0.1 |
| <i>F. culmorum</i> | <1 | 30 | <1 | <1 | – | 0.2 | <0.1 | <0.1 |
| <i>F. graminearum</i> | 17 | 49 | 42 | 8 | – | 0.6 | 0.4 | <0.1 |
| <i>F. poae</i> | 30 | 30 | 26 | 55 | – | 0.1 | 0.2 | 0.2 |
| <i>F. sporotrichioides</i> | 17 | 86 | 84 | <1 | – | 1.3 | 0.8 | <0.1 |
| FDK (2000–2001) | | | | | | | | |
| Percentage occurrence/ percentage FDK | – | 93 | 100 | – | – | 1.9 | 1.7 | – |
| Percentage FDK range | – | – | – | – | – | 0–20.0 | 0.1–13.2 | – |
| FDK attributed to | | | | | | | | |
| <i>F. avenaceum</i> | – | 86 | 65 | – | – | 0.7 | 0.3 | – |
| <i>F. culmorum</i> | – | 22 | 7 | – | – | 0.1 | 0.0 | – |
| <i>F. graminearum</i> | – | 50 | 43 | – | – | 0.4 | 0.5 | – |
| <i>F. poae</i> | – | 26 | 61 | – | – | 0.1 | 0.2 | – |
| <i>F. sporotrichioides</i> | – | 72 | 87 | – | – | 0.5 | 0.6 | – |

¹In 1999 FHB index attributed to the individual fungi was not calculated. The overall percentage isolation of these fungi was 18% for *F. avenaceum*, 8% for *F. graminearum*, 53% for *F. poae*, and 7% for *F. sporotrichioides*.

A previous year of summer fallow did not result in differences in FHB levels compared with barley grown after a crop (Table 2), except for FHB-*Fspo*, which was lowest for susceptible cultivars grown after a year of sum-

mer fallow (0.5%) than after a crop (0.7–1.4%) (data by cultivar susceptibility not presented). Barley grown after a sequence that included a cereal or noncereal crop and summer fallow (C–F, NC–F) had FHB levels that were also not significantly different than for barley grown after two consecutive crops. The exceptions were FHB-*Fav* and FHB-*Fg*, which were significantly higher in barley grown after NC–F than C–C (Table 2), and FHB-*Fp*, which was higher after NC–F than NC–NC ($P = 0.079$).

Because of the small sample size for tillage systems other than MT in most of the cropping sequences, tillage analysis was performed on all barley crops, regardless of the cropping sequence. Overall, there were no significant tillage effects, but interactions with cultivar susceptibility were significant in most cases (Table 2). For most of the fungi, differences between FHB indices in barley grown under CT and reduced tillage varied with cultivar susceptibility. For total FHB index, FHB-*Fg*, and FHB-*Fspo*, susceptible cultivars had the lowest disease levels under CT, whereas cultivars with intermediate resistance had the lowest levels under ZT; barley grown under MT had similar or higher disease levels than that grown under the other tillage systems.

FDK and Crop Production Factors

There were no significant interactions between previous crop or cropping sequences with cultivar susceptibility. Percentage FDK-total and FDK-*Fav* in 2000 and 2001 tended to be higher in barley grown after a pulse crop than after the other crops, but not significantly so at $P < 0.10$ (Table 3). In contrast, FDK-*Fg* and FDK-*Fp* were lower in barley grown after a pulse than other crops, although significantly so only for the former, whereas FDK-*Fspo* was significantly lower in barley grown after an oilseed.

A previous year of summer fallow had consistent effects on most of the fungi colonizing barley kernels and on the total percentage FDK (Table 3). Barley grown immediately after summer fallow had significantly lower FDK-total, FDK-*Fav*, FDK-*Fp*, and FDK-*Fspo* levels than for the other previous crops combined.

Table 2. Effect of crop susceptibility, tillage system and previous crop(s), and their interactions, on total Fusarium head blight (FHB) index, and on that attributed to *F. avenaceum* (FHB-*Fav*), *F. graminearum* (FHB-*Fg*), *F. poae* (FHB-*Fp*), and *F. sporotrichioides* (FHB-*Fspo*) in barley crops sampled in Crop Districts 1B and 5A in eastern Saskatchewan, 1999–2002.

| Effect, contrast | Number of crops | FHB-total | FHB- <i>Fav</i> | FHB- <i>Fg</i> | FHB- <i>Fp</i> | FHB- <i>Fspo</i> |
|---------------------------------|-----------------|-----------|-----------------|----------------|----------------|------------------|
| <hr/> | | | | | | |
| Cultivar susceptibility (CS) | | 0.038 | <0.001 | 0.086 | 0.914 | 0.156 |
| <hr/> | | | | | | |
| Mean % (SE) | | | | | | |
| Susceptible cultivars | 85 | 1.9 (0.3) | 0.4 (0.1) | 0.6 (0.2) | 0.1 (0.1) | 0.9 (0.2) |
| Intermediate cultivars | 102 | 1.3 (0.2) | 0.2 (<0.1) | 0.2 (<0.1) | 0.2 (<0.1) | 0.6 (0.1) |
| <hr/> | | | | | | |
| P value | | | | | | |
| Previous crop | | 0.978 | 0.039 | 0.002 | 0.543 | 0.198 |
| Cereal vs. oilseed | | 0.753 | 0.091 | 0.149 | 0.205 | 0.059 |
| Cereal vs. pulse | | 0.820 | 0.008 | 0.014 | 0.707 | 0.846 |
| Oilseed vs. pulse | | 0.948 | 0.114 | 0.029 | 0.649 | 0.209 |
| Oilseed vs. cereal, pulse | | 0.835 | 0.670 | 0.068 | 0.303 | 0.043 |
| Pulse vs. cereal, oilseed | | 0.933 | 0.027 | 0.006 | 0.989 | 0.617 |
| <hr/> | | | | | | |
| Mean % (SE) | | | | | | |
| Cereal | 74 | 1.8 (0.3) | 0.2 (0.1) | 0.3 (0.1) | 0.2 (0.1) | 1.0 (0.2) |
| Oilseed | 86 | 1.4 (0.3) | 0.3 (0.1) | 0.5 (0.2) | 0.1 (<0.1) | 0.5 (0.1) |
| Pulse | 13 | 1.5 (0.4) | 0.6 (0.2) | <0.1 (<0.1) | 0.2 (0.1) | 0.9 (0.3) |
| Summer fallow | 19 | 1.6 (0.4) | 0.2 (0.1) | 0.2 (0.1) | 0.2 (0.1) | 0.7 (0.2) |
| <hr/> | | | | | | |
| P value | | | | | | |
| Previous two crops ¹ | | 0.994 | <0.001 | 0.119 | 0.075 | 0.929 |
| C–C vs. C–NC, NC–NC | | 0.907 | 0.000 | 0.054 | 0.239 | 0.396 |
| C–C vs. NC–F | | 0.724 | 0.000 | 0.080 | 0.539 | 0.502 |
| <hr/> | | | | | | |
| Mean % (SE) | | | | | | |
| C–C | 24 | 1.5 (0.5) | <0.1 (<0.1) | 0.1 (<0.1) | 0.2 (0.1) | 1.1 (0.5) |
| C–NC | 112 | 1.5 (0.2) | 0.3 (0.1) | 0.4 (0.2) | 0.1 (<0.1) | 0.6 (0.1) |
| NC–NC | 13 | 1.6 (0.5) | 0.5 (0.2) | 0.7 (0.4) | <0.1 (<0.1) | 0.6 (0.3) |
| C–F | 18 | 2.3 (0.5) | 0.3 (0.1) | 0.2 (0.1) | 0.2 (0.1) | 1.0 (0.3) |
| NC–F | 23 | 1.6 (0.4) | 0.4 (0.1) | 0.4 (0.2) | 0.3 (0.1) | 0.7 (0.2) |
| <hr/> | | | | | | |
| P value | | | | | | |
| Tillage system ² | | 0.020 | 0.853 | 0.049 | 0.066 | 0.003 |
| CS × tillage system | | 0.006 | 0.630 | 0.014 | 0.311 | 0.001 |
| <hr/> | | | | | | |
| Mean % (SE) | | | | | | |
| Susceptible cultivars | | | | | | |
| CT | 20 | 1.1 (0.3) | 0.5 (0.2) | 0.1 (0.1) | 0.4 (0.3) | 0.4 (0.1) |
| MT | 47 | 2.1 (0.5) | 0.4 (0.1) | 0.7 (0.3) | 0.1 (<0.1) | 0.9 (0.2) |
| ZT | 18 | 2.2 (0.6) | 0.4 (0.1) | 0.5 (0.3) | 0.3 (0.2) | 1.2 (0.5) |
| Intermediate cultivars | | | | | | |
| CT | 13 | 1.9 (0.4) | 0.3 (0.1) | 0.3 (0.1) | 0.1 (<0.1) | 1.3 (0.3) |
| MT | 65 | 1.4 (0.3) | 0.2 (<0.1) | 0.2 (0.1) | 0.2 (0.1) | 0.7 (0.2) |
| ZT | 24 | 0.5 (0.1) | 0.2 (0.1) | <0.1 (<0.1) | 0.1 (<0.1) | 0.2 (0.1) |

¹Categorization of cultivars into "Susceptible" ("Poor") and "Intermediate" ("Fair" or "Fair+") is based on information presented in Saskatchewan Agriculture, Food and Rural Revitalization (2005) for each cultivar.

²C, cereal; NC, noncereal; F, summer fallow. Barley crops grouped according to previous two crops or summer fallow, regardless of the order in the sequence (C–C, C–NC, NC–NC, C–F, and NC–F).

³CT, conventional-till; MT, minimum-till; ZT, zero-till.

Furthermore, percentage FDK-total and FDK-*Fspo* were significantly lower after sequences that included a year of summer fallow (C-F, NC-F) than after continuously cropped sequences. In addition, percentage FDK-*Fav* was also significantly lower after C-F than after C-NC. Percentage FDK-*Fg* also tended to be lower when barley was grown immediately after summer fallow, or after 2-yr sequences that included summer fallow, than when grown after a crop or continuously cropped sequences. Lower levels of FDK-total and FDK-*Fg* after C-F and NC-F than after the other cropping sequences is mostly attributed to their high levels after sequences that included at least one noncereal crop (C-NC, NC-NC).

Analysis of the FDK data by tillage system for all cropping sequences combined showed that for the most part, there were no significant interactions of tillage system with cultivar susceptibility. Barley grown under MT management had significantly higher percentage total FDK, FDK-*Fg*, and FDK-*Fp* than barley in the other tillage systems combined (Table 3). Lowest levels of FDK-*Fg* and FDK-*Fp* were observed under ZT, whereas lowest levels of FDK-*Fspo* were observed under CT, resulting in the latter being the only FHB index that was significantly different for CT than for reduced tillage (MT and ZT) ($P = 0.007$).

Herbicide Effects on FHB

Analysis of herbicide use in the previous 18 mo according to previous crop or summer fallow in fields under MT management showed that for Group 1 herbicides, barley fields preceded by summer fallow constituted a greater proportion of the unsprayed fields than for the other herbicide groups (Table 4). Compared to the other herbicide groups, for glyphosate (Group 9 herbicides) there was a greater percentage of barley crops preceded by a cereal crop in fields that had not been sprayed in the previous 18 mo, and a greater percentage of barley crops preceded by an oilseed crop (mostly canola) in fields that had been sprayed. Of all the Group 9-treated barley fields under MT management preceded by an oilseed crop, more than 40% of them had received in-crop applications of glyphosate, suggesting that many of these were herbicide-tolerant canola cultivars.

The analysis of the effect of previous herbicide use (yes/no) on FHB levels was done for each of the tillage systems, although sample size for treated and/or untreated fields was lower for CT- and ZT- than for MT-managed fields. Overall, the interaction of herbicide group application \times cultivar susceptibility

was not significant ($P > 0.10$), and in most cases, there were no significant effects of previous herbicide use on the total FHB index and the FHB indices attributed to the individual fungi (Table 5). For barley crops under MT management, previous Group 1 use in barley fields was associated with a significantly higher level of FHB-*Fp*, whereas Group 9 use was associated with a significantly higher level of FHB-*Fav* than in barley grown in untreated fields. Similarly, for barley crops under ZT, a significant increase in the total FHB index and FHB-*Fspo* was associated with previous Group 1 use, whereas significant increases in the total FHB index, FHB-*Fg*, and FHB-*Fspo* were associated with previous applications of Group 9 herbicides. For barley grown under CT, there were also significantly higher FHB-total, FHB-*Fp*, and FHB-*Fspo* levels in fields that had received Group 9 herbicide applications than in those that had not; in contrast, significant reductions in FHB-*Fav* were associated with Group

Table 3. Effect of previous crop(s) and tillage system on total percentage *Fusarium*-damaged kernels (FDK), and on that attributed to *F. avenaceum* (FDK-*Fav*), *F. graminearum* (FDK-*Fg*), *F. poae* (FDK-*Fp*), and *F. sporotrichoides* (FDK-*Fspo*), in barley crops sampled in Crop Districts 1B and 5A in eastern Saskatchewan, 2000 and 2001.

| Effect, contrast | Number of crops | FDK-total | FDK- <i>Fav</i> | FDK- <i>Fg</i> | FDK- <i>Fp</i> | FDK- <i>Fspo</i> |
|---------------------------------|-----------------|-------------|-----------------|----------------|----------------|------------------|
| <hr/> | | | | | | |
| | | P value | | | | |
| Previous crop | | 0.002 | 0.065 | 0.276 | 0.172 | <0.001 |
| Oilseed vs. cereal, pulse | | 0.216 | 0.135 | 0.309 | 0.671 | 0.067 |
| Pulse vs. cereal, oilseed | | 0.189 | 0.172 | 0.053 | 0.135 | 0.191 |
| Summer fallow vs. others | | 0.001 | 0.020 | 0.110 | 0.067 | 0.004 |
| | | Mean % (SE) | | | | |
| Cereal | 38 | 2.0 (0.4) | 0.5 (0.2) | 0.4 (0.2) | 0.2 (0.1) | 0.7 (0.1) |
| Oilseed | 47 | 1.7 (0.4) | 0.4 (0.1) | 0.6 (0.3) | 0.2 (<0.1) | 0.4 (0.1) |
| Pulse | 8 | 3.6 (1.3) | 1.4 (0.7) | 0.1 (0.1) | 0.1 (<0.1) | 1.5 (0.7) |
| Summer fallow | 14 | 0.7 (0.1) | 0.2 (0.1) | 0.1 (0.1) | 0.1 (<0.1) | 0.2 (<0.1) |
| | | P value | | | | |
| Previous two crops ¹ | | 0.024 | 0.256 | 0.502 | 0.427 | 0.001 |
| C-F vs. C-NC | | 0.005 | 0.053 | 0.176 | 0.124 | 0.000 |
| C-F, NC-F vs. others | | 0.063 | 0.577 | 0.162 | 0.605 | 0.030 |
| | | Mean % (SE) | | | | |
| C-C | 10 | 1.3 (0.4) | 0.4 (0.1) | 0.2 (0.1) | 0.1 (0.1) | 0.6 (0.2) |
| C-NC | 56 | 2.3 (0.5) | 0.6 (0.2) | 0.6 (0.3) | 0.2 (<0.1) | 0.7 (0.1) |
| NC-NC | 9 | 2.0 (0.9) | 0.4 (0.1) | 0.6 (0.4) | 0.1 (0.1) | 0.8 (0.6) |
| C-F | 16 | 1.1 (0.3) | 0.3 (0.1) | 0.2 (0.1) | 0.1 (0.1) | 0.3 (0.1) |
| NC-F | 16 | 1.3 (0.4) | 0.5 (0.2) | 0.3 (0.1) | 0.2 (0.1) | 0.3 (0.1) |
| | | P value | | | | |
| Tillage system ² | | 0.046 | 0.309 | 0.014 | 0.002 | 0.001 |
| MT vs. CT, ZT | | 0.017 | 0.204 | 0.070 | 0.021 | 0.330 |
| | | Mean % (SE) | | | | |
| CT | 20 | 1.2 (0.2) | 0.4 (0.1) | 0.3 (0.1) | 0.2 (0.1) | 0.2 (0.1) |
| MT | 68 | 2.2 (0.4) | 0.6 (0.1) | 0.6 (0.2) | 0.2 (<0.1) | 0.6 (0.1) |
| ZT | 19 | 1.1 (0.4) | 0.3 (0.1) | <0.1 (<0.1) | <0.1 (<0.1) | 0.7 (0.3) |

¹C, cereal; NC, noncereal; F, summer fallow. Barley crops grouped according to previous two crops or summer fallow, regardless of the order in the sequence (C-C, C-NC, NC-NC, C-F, and NC-F).

²CT, conventional-till; MT, minimum-till; ZT, zero-till.

Table 4. Percentage of crops grown under minimum-till management, untreated or treated with herbicides belonging to different groups in the previous 18 mo, according to previous crop or summer fallow for barley crops sampled in Crop Districts 1B and 5A in eastern Saskatchewan, 1999–2002.

| Previous crop | | Group 1 | | Group 2 | | Group 4 | | Group 9 | |
|---------------|--------------------|-----------------|-----|---------|-----|---------|-----|---------|-----|
| | | No [†] | Yes | No | Yes | No | Yes | No | Yes |
| % | | | | | | | | | |
| Cereal | % crops | 23 [‡] | 47 | 33 | 48 | 36 | 41 | 66 | 29 |
| | No. of crops | 5 | 42 | 20 | 27 | 12 | 34 | 27 | 21 |
| Oilseed | % crops | 45 | 42 | 45 | 43 | 48 | 43 | 15 | 58 |
| | No. of crops | 10 | 38 | 27 | 24 | 16 | 35 | 6 | 42 |
| Pulse | % crops | 0 | 7 | 2 | 18 | 0 | 6 | 2 | 5 |
| | No. of crops | 0 | 5 | 1 | 4 | 0 | 5 | 1 | 4 |
| Summer fallow | % crops | 32 | 7 | 20 | 2 | 15 | 10 | 17 | 8 |
| | No. of crops | 7 | 5 | 12 | 1 | 5 | 8 | 7 | 6 |
| | Total no. of crops | 22 | 90 | 60 | 56 | 33 | 82 | 41 | 73 |

[†]No, no herbicide of this group applied in the previous 18 mo; Yes, herbicide of this group applied at least once in the previous 18 mo.

[‡]Percentage of fields on which herbicide of this group was or was not applied.

2, and significant reductions in total FHB index, FHB-*Fp*, and FHB-*Fspo* were associated with previous use of Group 4 herbicides.

The correlation between the total number of Group 9 herbicide applications to barley fields in the previous 18 mo and percentage FHB-*Fav* was significant for barley crops grown under MT; however, further analysis by susceptibility of barley showed that the correlation between the number of previous glyphosate applications and FHB-*Fg* or FHB-*Fav* was significant ($P < 0.01$) for cultivars with intermediate resistance but not for susceptible cultivars (Table 6). Similar correlations for the other FHB indices and for other herbicide groups were not significant ($P > 0.10$) (data not presented). For the same barley crops with intermediate resistance to FHB grown under MT, correlations between the number of tillage operations in the previous 3 yr and percentage FHB-*Fg* or FHB-*Fav* were not significant ($P > 0.10$) (data not presented), suggesting that the association of disease levels with previous Group 9 herbicide use was not attributed to the degree of tillage intensity.

DISCUSSION

Overall, FHB levels in barley crops sampled were lower than in eastern areas of the Canadian Prairies where this disease has become well established and has caused significant economic damage (Tekauz et al., 2003) but similar to what was reported from barley surveys conducted in Saskatchewan in the same years (Fernandez et al., 2000, 2001, 2002; Pearse et al., 2003). Similar to what was observed in spring wheat crops sampled for FHB in the same area and years (Fernandez et al., 2005), there was variation in FHB levels in barley among years, being highest in 2000 and 2001. As for wheat, percentage FDK in the harvested

barley grain samples was high enough in these 2 yr to cause downgrading of the grain based on threshold levels established by the Canadian Grain Commission (2006).

The frequency of the fungi isolated from affected spikes and grain was also similar to what was reported from the province-wide Saskatchewan surveys of barley crops (Fernandez et al., 2000, 2001, 2002; Pearse et al., 2003). Although the relative frequency of fungi isolated from infected barley spikes in this study differed from those isolated in a parallel study of common and durum (*T. turgidum* L. var. *durum*) wheat (Fernandez et al., 2005), *F. avenaceum* was among the most commonly isolated fungi for both wheat and barley. In Manitoba, although the most widespread and commonly isolated species from FHB-affected barley has been *F. graminearum*, followed by *F. poae*, *F. sporotrichioides*, and *F. avenaceum* (Tekauz et al., 2003), *F. avenaceum* in 2005 was the second most commonly isolated species from FHB-affected barley crops sampled in that province (Tekauz et al., 2006).

In our study, the *Fusarium* species associated with FDK in the barley crops sampled have also been reported elsewhere as the most commonly isolated species from infected barley grain in the Canadian Prairies. Clear et al. (2000) reported that *F. graminearum*, followed by *F. poae*, *F. sporotrichioides*, and *F. avenaceum* were the most commonly isolated species from infected barley grain in Manitoba in 1995 to 1997, whereas *F. poae* and *F. avenaceum* prevailed in Saskatchewan. However, in the two previous years (1993–1994), *F. avenaceum* was the second most common species after *F. graminearum* in infected barley grain in Saskatchewan (Clear et al., 1996). Turkington et al. (2002) and Clear et al. (2000) reported *F. avenaceum* as the most commonly isolated species from barley FDK in 1995 to 1997 in Alberta, followed by *F. poae*. Relative to the other species, *F. sporotrichioides* was isolated at lower levels from infected barley kernels than spikes in our study, especially in 2000, suggesting that spike infection by this fungus did not always result in detectable kernel infections after harvest. However, there was a significant correlation between the FHB index and percentage FDK attributed to this fungus.

Analysis of the data by tillage system suggested that MT management favored disease development, especially percentage FDK. Rioux et al. (2005) reported that barley grown under MT had higher DON content than when grown under CT. The observation that overall barley grown under MT management had higher disease levels than barley grown under the other tillage systems agrees with the report by Fernandez et al. (2005) for common and durum wheat crops, which had a similar preponderance of oilseed as the previously grown crop.

A previous year of summer fallow affected FDK in 2000 and 2001 more than the overall mean FHB levels, reducing kernel infection by most fungi. Similar to the analysis of

the data from the 4 yr of this study, analysis of the 2000 and 2001 data only also showed that there were no significant differences in FHB levels between barley grown after summer fallow and when grown after a crop (separate analysis of 2000–2001 data not presented). Observations by Sturz and Johnston (1985) that overall *Fusarium* isolations from barley spikes were higher in barley grown on stubble than on summer fallow agree with results from our FDK analysis but not with the FHB data. On average, barley crops preceded by summer fallow, or by a year of summer fallow and a cereal crop, received lower N input than barley grown after the other sequences. While Martin et al. (1991) reported no consistent effects of added N on seed infection in barley caused by the same fungi as in our study, Lemmens et al. (2004) found significant increases in FHB and DON in wheat as a result of N fertilization, although higher rates of applied N (up to 160 kg N ha⁻¹) were used in their study compared to ours. However, because no soil N analysis was performed in our study, differences among cropping sequences for total N available are not known.

Fusarium avenaceum and *F. graminearum* on spikes were less prevalent in continuous cereal systems mostly under MT (C–C) than in continuous diversified systems (C–NC, NC–NC) under MT or ZT, or with a noncereal alternated with summer fallow (NC–F), mostly under CT or MT. However, levels of FHB–Fav and FHB–Fg in barley after C–C were similar to those in barley grown after a cereal alternated with summer fallow (C–F), which were also mostly under CT or MT management. These results suggest that cropping sequence had a greater impact on infection of barley by *F. avenaceum* and *F. graminearum* than tillage system and that noncereal crops appear to have played a more important role in disease development attributed to these fungi in succeeding barley crops than the presence of host cereal crops grown continuously in the previous 2 yr (C–C).

Table 5. Effect of herbicide use (previous 18 mo) on total *Fusarium* head blight (FHB) index, and FHB index attributed to *F. avenaceum* (FHB–Fav), *F. graminearum* (FHB–Fg), *F. poae* (FHB–Fp), and *F. sporotrichioides* (FHB–Fspo), of barley crops within each tillage system, sampled in Crop Districts 1B and 5A in eastern Saskatchewan, 1999–2002.

| Herbicide group | Tillage system ¹ | Herbicide use | Number of crops | FHB-total | FHB-Fav | FHB-Fg | FHB-Fp | FHB-Fspo |
|-----------------|-----------------------------|-----------------|-----------------|-----------|-----------|-----------|-----------|-----------|
| P value | | | | | | | | |
| Group 1 | CT | | | 0.105 | 0.194 | 0.177 | 0.238 | 0.270 |
| | MT | | | 0.454 | 0.146 | 0.158 | 0.034 | 0.837 |
| | ZT | | | 0.081 | 0.422 | 0.785 | 0.319 | 0.080 |
| Group 2 | CT | | | 0.878 | 0.069 | 0.306 | 0.928 | 0.421 |
| | MT | | | 0.752 | 0.513 | 0.550 | 0.897 | 0.867 |
| | ZT | | | 0.642 | 0.333 | 0.236 | 0.883 | 0.448 |
| Group 4 | CT | | | 0.099 | 0.000 | 0.069 | 0.000 | 0.065 |
| | MT | | | 0.292 | 0.338 | 0.349 | 0.107 | 0.968 |
| | ZT | | | 0.104 | 0.377 | 0.150 | 0.329 | 0.281 |
| Group 9 | CT | | | 0.017 | 0.841 | 0.121 | 0.071 | 0.001 |
| | MT | | | 0.465 | 0.010 | 0.375 | 0.585 | 0.801 |
| | ZT | | | 0.015 | 0.604 | 0.100 | 0.378 | 0.025 |
| Mean % (SE) | | | | | | | | |
| Group 1 | CT | No ² | 10 | 1.0 (0.3) | 0.3 (0.2) | 0.1 (0.1) | 0.1 (0.1) | 0.6 (0.3) |
| | CT | Yes | 11 | 1.9 (0.6) | 0.5 (0.2) | 0.3 (0.1) | 0.4 (0.2) | 1.1 (0.3) |
| | MT | No | 25 | 1.4 (0.5) | 0.2 (0.1) | 0.1 (0.1) | 0.1 (0.0) | 0.9 (0.4) |
| | MT | Yes | 99 | 1.6 (0.2) | 0.3 (0.0) | 0.4 (0.2) | 0.2 (0.0) | 0.7 (0.1) |
| | ZT | No | 14 | 0.6 (0.2) | 0.2 (0.1) | 0.1 (0.1) | 0.1 (0.0) | 0.1 (0.1) |
| | ZT | Yes | 29 | 1.5 (0.4) | 0.3 (0.1) | 0.2 (0.2) | 0.2 (0.1) | 0.8 (0.3) |
| Group 2 | CT | No | 15 | 1.5 (0.4) | 0.5 (0.2) | 0.1 (0.0) | 0.2 (0.2) | 0.6 (0.2) |
| | CT | Yes | 6 | 1.4 (0.6) | 0.1 (0.0) | 0.4 (0.2) | 0.2 (0.1) | 1.4 (0.5) |
| | MT | No | 66 | 1.6 (0.4) | 0.2 (0.1) | 0.4 (0.2) | 0.2 (0.1) | 0.7 (0.2) |
| | MT | Yes | 58 | 1.5 (0.2) | 0.2 (0.1) | 0.3 (0.1) | 0.2 (0.0) | 0.7 (0.1) |
| | ZT | No | 18 | 1.0 (0.3) | 0.1 (0.1) | 0.4 (0.3) | 0.2 (0.1) | 0.3 (0.2) |
| | ZT | Yes | 25 | 1.3 (0.4) | 0.3 (0.1) | 0.1 (0.0) | 0.2 (0.1) | 0.7 (0.3) |
| Group 4 | CT | No | 4 | 2.6 (1.3) | 1.4 (0.1) | 0.4 (0.0) | 1.1 (0.6) | 1.3 (0.3) |
| | CT | Yes | 17 | 1.2 (0.3) | 0.3 (0.1) | 0.1 (0.1) | 0.1 (0.0) | 0.8 (0.2) |
| | MT | No | 36 | 2.0 (0.6) | 0.2 (0.1) | 0.6 (0.4) | 0.3 (0.1) | 0.6 (0.2) |
| | MT | Yes | 88 | 1.4 (0.2) | 0.3 (0.1) | 0.2 (0.1) | 0.1 (0.0) | 0.7 (0.2) |
| | ZT | No | 9 | 0.8 (0.2) | 0.3 (0.2) | 0.1 (0.0) | 0.1 (0.0) | 0.4 (0.2) |
| | ZT | Yes | 34 | 1.3 (0.3) | 0.3 (0.1) | 0.2 (0.1) | 0.2 (0.1) | 0.6 (0.3) |
| Group 9 | CT | No | 14 | 0.8 (0.3) | 0.4 (0.2) | 0.1 (0.0) | 0.0 (0.0) | 0.4 (0.2) |
| | CT | Yes | 7 | 2.8 (0.7) | 0.4 (0.2) | 0.4 (0.2) | 0.6 (0.3) | 1.5 (0.4) |
| | MT | No | 47 | 1.4 (0.3) | 0.1 (0.0) | 0.2 (0.1) | 0.2 (0.0) | 0.7 (0.3) |
| | MT | Yes | 76 | 1.7 (0.3) | 0.3 (0.1) | 0.4 (0.2) | 0.2 (0.1) | 0.7 (0.1) |
| | ZT | No | 7 | 0.5 (0.3) | 0.3 (0.3) | 0.0 (0.0) | 0.1 (0.0) | 0.0 (0.0) |
| | ZT | Yes | 36 | 1.3 (0.3) | 0.3 (0.1) | 0.2 (0.1) | 0.2 (0.1) | 0.7 (0.2) |

¹CT, conventional-till; MT, minimum-till; ZT, zero-till.

²No, no herbicide of this group applied in the previous 18 mo; Yes, herbicide of this group applied at least once in the previous 18 mo.

There was also a differential effect of the previous noncereal crop on *F. avenaceum* and *F. graminearum* on spikes and kernels. Compared to other crops, a previous pulse crop favored an increase in FHB and FDK caused by *F. avenaceum*, but it resulted in a decrease in that associated with *F. graminearum*. Dill-Mackay and Jones (2000) also reported lower FHB and DON levels, attributed mostly to

Table 6. Correlation between number of Group 9 herbicide (glyphosate) applications in previous 18 mo and *Fusarium* head blight (FHB) index attributed to *F. avenaceum* (FHB-Fav) and *F. graminearum* (FHB-Fg), for all barley crops, and for susceptible cultivars and cultivars with intermediate resistance, grown under minimum-till, sampled in Crop Districts 1B and 5A in eastern Saskatchewan, 2000–2002.

| | Number of crops | FHB-Fav | FHB-Fg |
|--------------------------|-----------------|----------------|---------------|
| All crops | 112 | 0.234 (0.019)* | 0.146 (0.151) |
| Susceptible [†] | 47 | 0.115 (0.456) | 0.163 (0.289) |
| Intermediate | 62 | 0.439 (0.000) | 0.347 (0.005) |

*R value, P value in parentheses.

[†]Categorization of cultivars into "Susceptible" ("Poor") and "Intermediate" ("Fair" or "Fair+") is based on information presented in Saskatchewan Agriculture, Food and Rural Revitalization (2005) for each cultivar.

F. graminearum, in spring wheat grown after soybean [*Glycine max* (L.) Merr.] than after a wheat crop. In contrast, Rioux et al. (2005) reported that a previous forage crop of orchardgrass and red clover was more conducive to DON production in barley than when the preceding crop was another barley crop. Changes in the prevalence of FHB pathogens associated with the preceding crop have been reported before. Cromey et al. (2002) found that while *F. graminearum* was the predominant grain pathogen in spring wheat planted after corn (*Zea mays* L.), the percentage of grain infected by this pathogen decreased, and that of *F. avenaceum* and *F. poae* increased, in wheat planted after other crops.

The increase in disease levels caused by *F. avenaceum* after pulse crops could be attributed to the susceptibility of pulses to this pathogen (Hwang et al., 2000). In the same area that this study was conducted, *F. avenaceum* was found at higher levels in pulse than in cereal or canola roots and residues (Fernandez, 2007; Fernandez et al., 2003a).

Fusarium avenaceum and *F. graminearum* tended to be present at similar or higher levels on barley spikes when grown after an oilseed than a cereal crop. Canola and flax (*Linum usitatissimum* L.) stem residues from the cereal fields sampled in this area were also shown to have a higher percentage isolation of *F. avenaceum* than cereal residues (Fernandez et al., 2003a), suggesting that oilseed residues could be an important source of inoculum for this pathogen. Correlations between FHB-Fav and FDK-Fav in susceptible barley cultivars with percentage *F. avenaceum* isolation from crop residues collected in the same fields at the time of sampling of the barley spikes were significant for oilseed ($r = 0.496$ for FHB-Fa, $r = 0.457$ for FDK-Fa, $P < 0.05$) but not for cereal residues ($P > 0.10$) (Fernandez, unpublished data). The similar or higher *F. graminearum* levels in barley grown after an oilseed crop (mostly canola) or after diversified sequences involving mostly canola crops partly agrees with Obst et al. (1997), who did not find any differences in DON levels between winter wheat grown after canola than after another cereal crop; however, Rioux et al. (2005) reported that barley grown in rotation with canola

had lower DON levels. The lack of an effect of a previous oilseed crop on FHB-Fg levels in barley could be partly explained by the colonization by *F. graminearum* of stem residues (Fernandez et al., 2003a) and roots (Fernandez, 2007) of these crops; however, isolation of this pathogen from oilseed tissue was low. Most previous oilseed crops were preceded by a cereal crop 2 yr previous to the barley crop sampled, and these older residues may have also been an inoculum source. However, it is not known why *F. graminearum* levels in barley were lowest when preceded by two cereal crops, given that inoculum levels would have been expected to be higher than when a noncereal crop was included in the sequence. The significantly higher grain yields of the same barley crops when they followed an oilseed versus a cereal crop (Fernandez et al., 2007) suggests that a previous oilseed crop may have resulted in a higher N status in the subsequent barley crop. In addition, barley fields preceded by two cereal crops had also received on average less N input (55 kg ha^{-1}) than when a noncereal crop was included in the sequence (65 kg ha^{-1}), and also had significantly lower grain yield than when there was at least one noncereal crop in the previous 2 yr, as reported by Fernandez et al. (2007). The higher N availability when a noncereal crop was included in the sequence may have affected FHB development (Lemmens et al., 2004). Other unknown factors related to the presence of oilseed crops may have also contributed to FHB development in the barley crops grown afterward in those fields.

However, based on the previous herbicide use pattern in barley fields analyzed according to the previously grown crop, and on the association of herbicide use with disease levels, it appears that the use of Group 9 (glyphosate) herbicides, in fields preceded mostly by an oilseed crop, were also associated with increased levels of all *Fusarium* pathogens, although these effects varied with tillage system. Some of these Group 9 herbicide applications had been done in-crop, indicating that they were done on glyphosate-tolerant canola. However, due to the nature of this study and the small sample size for unsprayed barley fields preceded by an oilseed crop, it was not possible to separate the impact of previously grown oilseed crops from that of previous Group 9 herbicide applications on disease levels. The other herbicides associated with significant increases in FHB levels attributed to *F. poae* and *F. sporotrichioides* belonged to Group 1, although this again depended on tillage system. According to the herbicide-use pattern in fields under MT, there were as many fields preceded by a cereal as by an oilseed crop sprayed with Group 1 herbicides, and more previous cereal crops than for Group 9. Although according to the analysis of the effect of previous crop on disease levels previous cereal crops resulted in significantly higher levels of FHB-Fpo on the succeeding barley crops, as for Group 9, it was not possible to separate the effect of previous crop from that of Group 1 herbicide use on *Fusarium* infections.

The association of previous Group 9 herbicide applications with FHB levels is similar to the observations made for spring wheat regarding total FHB index, FHB-Fg, and FHB-Fav (Fernandez et al., 2003b; Fernandez et al., 2005). The wheat study did not find any significant effect of the other herbicide groups on disease levels. As indicated for wheat, the mechanism(s) responsible for the increase in disease levels in barley associated with previous Group 9 herbicide use is not known. However, based on the correlations between the total number of Group 9 herbicide applications in the previous 18 mo and FHB-Fg and FHB-Fav levels in barley crops, it is apparent that the impact of this herbicide on disease levels was greater for cultivars with intermediate resistance than for susceptible cultivars, suggesting that cultivar susceptibility may override the apparent impact of Group 9 herbicides on disease levels. Barley crops with intermediate resistance grown under MT management in fields that had received two glyphosate applications in the previous 18 mo had similar or slightly lower mean percentage FHB-Fav (0.4%) and FHB-Fg (0.5%) than the mean for all susceptible barley crops grown under MT (0.4 and 0.7%, respectively). In a parallel study of common root rot of the same barley crops sampled in this study (Fernandez et al., 2007), glyphosate was found to be the only herbicide associated with significant increases in *Fusarium* levels in subcrown internodes in fields under MT management.

According to Fernandez et al. (2007), the other crop production factors that affected *Fusarium* infections on spikes in this study were also similar to those that affected the percentage isolation of *Fusarium* spp. from subcrown internodes of the same barley crops sampled from 1999 to 2001. The similar impact of production factors on FHB and common root rot points to the importance of agronomic practices vis-à-vis the environment in the development of these barley diseases in eastern Saskatchewan.

Based on our observations, we conclude that growing barley under MT management where glyphosate had been applied, and in continuous diversified rotations, would result in the most damage due to FHB caused by two of the most important pathogens in this and other affected regions, *F. graminearum* and *F. avenaceum*. It is not known if barley grown in areas with traditionally higher FHB levels or where *F. graminearum* is the predominant pathogen would be more or less impacted by the same crop production factors. In any case, determining the relative contribution of cropping sequence, tillage method, and herbicide applications to FHB development in barley can assist in devising the most appropriate agronomic recommendations for its control.

Considering that currently popular production practices appear to be associated with FHB development in this region, and based on the importance of *F. avenaceum*, a wide-host range pathogen, relative to the other *Fusarium* patho-

gens, breeding for resistance to FHB seems to be the most practical way of controlling this important cereal disease. Furthermore, incorporating resistance to *Fusarium* infections in roots and crowns may also be important for controlling the development and spread of FHB in barley on the western Canadian Prairies. However, determining the mechanism responsible for the association of previous glyphosate applications with spike infections caused by *F. graminearum* and *F. avenaceum* would help in disease control and possibly in maintaining the resistance of barley to this important disease.

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References

- Abramson, D., B. McCallum, D.M. Smith, and A. Tekauz. 2002. Moniliformin in barley inoculated with *Fusarium avenaceum*. Food Addit. Contam. 19:765-769.
- Burgess, L.W., C.M. Liddell, and B.A. Summerell. 1988. Laboratory manual for *Fusarium* research. 2nd ed. Univ. of Sidney, Sidney, Australia.
- Campbell, C.A., R.P. Zentner, S. Gameda, B. Blomert, and D.D. Wall. 2002. Production of annual crops on the Canadian prairies: Trends during 1976-1998. Can. J. Soil Sci. 82:45-57.
- Campbell, H., T.M. Choo, B. Vigier, and L. Underhill. 2000. Mycotoxins in barley and oat samples from eastern Canada. Can. J. Plant Sci. 80:977-980.
- Canadian Grain Commission. 2005. Official grain grading guide. Available at <http://www.grainscanada.gc.ca/Pubs/GGG/ggg-e.htm> (verified 22 May 2007). Canadian Grain Commission, Winnipeg, MB.
- Clear, R.M., S.K. Patrick, and D. Gaba. 2000. Prevalence of fungi and fusariotoxins on barley seed from western Canada, 1995 to 1997. Can. J. Plant Pathol. 22:44-50.
- Clear, R.M., S.K. Patrick, R.G. Platford, and M. Desjardins. 1996. Occurrence and distribution of *Fusarium* species in barley and oat seed from Manitoba in 1993 and 1994. Can. J. Plant Pathol. 18:409-414.
- Cromey, M.G., S.C. Shorter, D.R. Lauren, and K.I. Sinclair. 2002. Cultivar and crop management influences on *Fusarium* head blight and mycotoxins in spring wheat (*Triticum aestivum*) in New Zealand. N. Z. J. Crop Hortic. Sci. 30:235-247.
- Dill-Macky, R., and R.K. Jones. 2000. The effect of previous crop residues and tillage on *Fusarium* head blight of wheat. Plant Dis. 84:71-76.
- Environment Canada. 2003. Climate archive. Available at http://www.climate.weatheroffice.ec.gc.ca/climateData/monthlydata_e.html (verified 12 Apr. 2007). Environment Canada, Quebec.
- Fernandez, M.R. 2007. *Fusarium* populations in roots of oilseed and pulse crops grown in eastern Saskatchewan. Can. J. Plant Sci. (in press).
- Fernandez, M.R., and Y. Chen. 2005. Pathogenicity of *Fusarium* species on different plant parts of spring wheat under controlled conditions. Plant Dis. 89:164-169.
- Fernandez, M.R., P.G. Pearse, and G. Holzgang. 2003a. *Fusarium* spp. in residues of cereal and noncereal crops grown in rotation

- in eastern Saskatchewan. *Can. J. Plant Pathol.* 25:423.
- Fernandez, M.R., P.G. Pearse, G. Holzgang, and G.R. Hughes. 2000. Fusarium head blight in barley in Saskatchewan in 1999. *Can. Plant Dis. Surv.* 80:32–33.
- Fernandez, M.R., P.G. Pearse, G. Holzgang, and G.R. Hughes. 2001. Fusarium head blight in barley in Saskatchewan in 2000. *Can. Plant Dis. Surv.* 81:61–62.
- Fernandez, M.R., P.G. Pearse, G. Holzgang, and G.R. Hughes. 2002. Fusarium head blight in barley in Saskatchewan in 2001. *Can. Plant Dis. Surv.* 82:32–33.
- Fernandez, M.R., F. Selles, D. Gehl, R.M. DePauw, and R.P. Zentner. 2003b. Identification of crop production factors associated with the development of Fusarium head blight in spring wheat in southeast Saskatchewan. Report to Saskatchewan Agriculture Development Fund, Project No. 98000306. Saskatchewan, Canada.
- Fernandez, M.R., F. Selles, D. Gehl, R.M. DePauw, and R.P. Zentner. 2005. Crop production factors associated with Fusarium head blight in spring wheat in eastern Saskatchewan. *Crop Sci.* 45:1908–1916.
- Fernandez, M.R., R.P. Zentner, R.M. DePauw, D. Gehl, and F.C. Stevenson. 2007. Impacts of crop production factors on common root rot of barley and associated fungi in eastern Saskatchewan, Canada. *Crop Sci.* 47:1585–1595.
- Hwang, S.F., B.D. Gossen, G.D. Turnbull, K.F. Chang, R.J. Howard, and A.G. Thomas. 2000. Effect of temperature, seeding date, fungicide seed treatment and inoculation with *Fusarium avenaceum* on seedling survival, root rot severity, and yield of lentil. *Can. J. Plant Sci.* 80:899–907.
- Lemmens, M., K. Haim, H. Lew, and P. Ruckebauer. 2004. The effect of nitrogen fertilization on Fusarium head blight development and deoxynivalenol contamination in wheat. *J. Phytopathol.* 152:1–8.
- Martin, R.A., J.A. MacLeod, and C. Caldwell. 1991. Influences of production inputs on incidence of infection by *Fusarium* species on cereal seed. *Plant Dis.* 75:784–788.
- Miller, J.D., J. Culley, K. Fraser, S. Hubbard, F. Meloche, T. Ouellet, W.L. Seaman, K.A. Seifert, K. Turkington, and H. Voldeng. 1998. Effect of tillage practice on Fusarium head blight of wheat. *Can. J. Plant Pathol.* 20:95–103.
- Obst, A., J. Lepeschy von Gleissenthall, and R. Beck. 1997. On the etiology of Fusarium head blight of wheat in south Germany: Preceding crops, weather conditions for inoculum production and head infection, proneness of the crop to infection and mycotoxin production. *Cereal Res. Commun.* 25:699–703.
- Padbury, G., S. Waltman, J. Caprio, G. Coen, S. McGinn, D. Mortensen, G. Neilsen, and R. Sinclair. 2002. Agroecosystems and land resources of the northern Great Plains. *Agron. J.* 94:251–261.
- Pearse, P.G., G. Holzgang, C.L. Harris, and M.R. Fernandez. 2003. Fusarium head blight in barley in Saskatchewan in 2002. *Can. Plant Dis. Surv.* 83:48–49.
- Pearse, P.G., G. Holzgang, C.L. Harris, and M.R. Fernandez. 2006. Fusarium head blight in barley and oat in Saskatchewan in 2005. *Can. Plant Dis. Surv.* 86:45–46.
- Rioux, S., D. Pageau, J. Lajeunesse, J. Lafond, and M.E. Savard. 2005. Previous crop residues and Fusarium head blight on cereals. In *Proc. of the 4th Canadian Workshop on Fusarium Head Blight*. 1–3 Nov. Ottawa, ON.
- Salas, B., B.J. Steffenson, H.H. Casper, B. Tacke, L.K. Prom, T.G. Fetch, Jr., and P.B. Schwarz. 1999. *Fusarium* species pathogenic to barley and their associated mycotoxins. *Plant Dis.* 83:667–674.
- Samson, R.A., E.S. Hoekstra, J.C. Frisvad, and O. Filtenborg. 2002. Introduction to food and airborne fungi. 6th ed. Centraalbureau voor Schimmecultures, Utrecht, the Netherlands.
- SAS Institute. 1999. SAS OnlineDoc, version 8. SAS Inst., Cary, NC.
- Saskatchewan Agriculture and Food. 2006. 2006 guide to crop protection. Saskatchewan Agriculture and Food, SK.
- Saskatchewan Agriculture, Food and Rural Revitalization. 2005. Saskatchewan varieties of grain crops 2005. Saskatchewan Agriculture, Food and Rural Revitalization, Regina, SK.
- Schaafsma, A.W., L. Tamburic-Ilinic, J.D. Miller, and D.C. Hooker. 2001. Agronomic considerations for reducing deoxynivalenol in wheat grain. *Can. J. Plant Pathol.* 23:279–285.
- Sturz, A.V., and H.W. Johnston. 1985. Characterization of *Fusarium* colonization of spring barley and wheat produced on stubble or fallow soil. *Can. J. Plant Pathol.* 7:270–276.
- Tekauz, A., J. Gilbert, E. Mueller, M. Stulzer, and M. Bevene. 2006. Survey for Fusarium head blight of barley in Manitoba in 2005. *Can. Plant Dis. Surv.* 86:37–38.
- Tekauz, A., J. Gilbert, E. Mueller, M. Stulzer, M. Bevene, H. Ghazvini, R. Kaethler, and F. Reverchon. 2003. 2002 survey for Fusarium head blight of barley in Manitoba. *Can. Plant Dis. Surv.* 83:46–47.
- Tekauz, A., B. McCallum, and J. Gilbert. 2000. Review: Fusarium head blight of barley in western Canada. *Can. J. Plant Pathol.* 22:9–16.
- Turkington, T.K., R.M. Clear, P.A. Burnett, S.K. Patrick, D.D. Orr, and K. Xi. 2002. Fungal plant pathogens infecting barley and wheat seed from Alberta, 1995–1997. *Can. J. Plant Pathol.* 24:302–308.
- Watanabe, T. 2002. Pictorial atlas of soil and seed fungi. Morphologies of cultured fungi and key to species. 2nd ed. CRC Press, Boca Raton, FL.
- Zadoks, J.C., T.T. Chang, and C.F. Konzak. 1974. A decimal code for the growth stages of cereals. *Weed Res.* 14:415–421.

